Approval Standard for Clean Agent Extinguishing Systems

Class Number 5600

April 2013

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Foreword

Approvals are intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of Approval Standards is to present the criteria for Approval of various types of products and services, as guidance for FM Approvals personnel, manufacturers, users, and authorities having jurisdiction.

Products submitted for Approval shall demonstrate that they meet the intent of the Approval Standard, and that quality control in manufacturing and/or applications shall ensure a consistently uniform and reliable product or service. Approval Standards strive to be performance-oriented and to facilitate technological development.

For examining equipment, materials, and services, Approval Standards:

a) must be useful to the ends of property conservation by preventing, limiting or not causing damage under the conditions stated by the Approval listing; and

b) must be readily identifiable and readily available in the marketplace.

Continuance of Approval and Listing depends on compliance with the Master Agreement, satisfactory performance in the field, on successful re-examinations of equipment, materials, and services as appropriate, and on periodic surveillance audits of the manufacturing facility or service/application.

FM Approvals LLC reserves the right in its sole judgment to change or revise its standards, criteria, methods, or procedures.

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1. INTRODUCTION

1.1 Purpose

1.1.1 This standard describes requirements for fixed fire extinguishing systems which use vaporizing liquid or inert gas clean agents as the extinguishant.

1.1.2 FM Approvals criteria may include, but are not limited to, performance requirements, marking requirements, examination of manufacturing and filling facilities, audit of quality assurance procedures, and a surveillance audit program.

1.2 Scope

1.2.1 This standard contains requirements for vaporizing liquid and inert gas clean agent extinguishing systems for total flooding protection. Extinguishing systems shall be designed for automatic control to protect single or multiple hazard areas. The following product categories and class numbers are included in the scope of this standard.

Table 1.2.1 - *Product Categories and Class Numbers*

Class	***Product Category***
5611	Inert Gas Extinguishing Systems
5612	Liquefied Gas Extinguishing Systems
5613	Clean Agents

1.2.2 A basic vaporizing liquid or inert gas clean agent extinguishing system comprises one or more agent storage containers, discharge control valves arranged for automatic or manual/automatic control, lock-out valves (when required), piping, and discharge nozzles. Compatible FM Approved detectors and detection and release controls are required for automatic electrical operation of these systems, but are not included in the scope of this standard. If a system uses an integral detection and actuation system, it may be evaluated as a part of that system, using criteria derived from those used for standalone detection and control systems.

1.2.3 This standard requires the examination of complete systems. Complete systems shall be submitted along with design, installation, operation, and maintenance instructions for Approval. However, the manufacturer may, at any time, submit additional components or auxiliary equipment for use on the Approved system. Purchased devices such as thermostats, releases, and timers must also be submitted by the system manufacturer for evaluation as a part of the system, even though such devices may already be FM Approved and listed by FM Approvals. At minimum, a system shall consist of those components and auxiliary equipment considered necessary by FM Approvals for the system to operate properly when connected to an Approved detection and control system. Incomplete systems shall not be FM Approved.

1.3 Basis for Requirements

1.3.1 The requirements of this standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions, and/or loss control specialists has also been considered.

1.3.2 The requirements of this standard reflect tests and practices used to examine characteristics of clean agent fire extinguishing systems (hereinafter referred to as “systems”) for the purpose of obtaining FM Approval. Systems having characteristics not anticipated by this standard may be FM Approved if performance equal or superior to that required by this standard is demonstrated, or if the intent of the standard is met.

Alternatively, systems which meet all of the requirements identified in this standard may not be FM Approved if other conditions which adversely affect performance exist, or if the intent of this standard is not met.

1.4 Basis for FM Approval

FM Approval is based on satisfactory evaluation of the product and the manufacturer in the following areas:

1.4.1 Examination and tests on production samples shall be performed to evaluate:

- The suitability of the product
- The performance of the product as specified by the manufacturer and required by FM Approvals
- The durability and reliability of the product

1.4.2 Surveillance audits of the manufacturing and filling facilities and quality control procedures shall made to evaluate the manufacturer's ability to produce the product which was examined and tested, and the marking procedures used to identify the product. These examinations are repeated as part of FM Approvals' surveillance audit program.

1.5 Basis for Continued Approval

Continued Approval is based on:

- Production or availability of the product as currently FM Approved
- Continued use of acceptable quality assurance procedures
- Satisfactory field experience
- Compliance with the terms stipulated in the Approval Agreement
- Satisfactory re-examination of production samples for continued conformity to requirements.
- Satisfactory audits conducted as part of FM Approvals' Surveillance Audit program.

Also, as a condition of retaining Approval, manufacturers may not change a product or service without prior authorization by FM Approvals (refer to Section 5.1.4).

1.6 Effective Date

The effective date of an Approval standard mandates that all products tested for Approval after that date shall satisfy the requirements of the standard. Products FM Approved under a previous edition shall comply with the new version by the effective date or forfeit Approval.

The effective date of this standard is **One Year from date of Issue** for full compliance with all requirements.

1.7 System of Units

Units of measurement used in this standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement; the converted equivalent value may be approximate. Appendix A lists the selected units and conversions to SI units for measures appearing in this standard. Conversion of U.S. customary units is in accordance with the Institute of Electrical and Electronics Engineers (IEEE)/American Society for Testing Materials (ASTM) SI 10-2002*, American National Standard for Use of the International System of Units (SI): The Modern Metric System.* Two units of measurement (liter and bar), outside of but recognized by SI, are commonly used in international fire protection and are used in this standard.

1.8 Applicable Documents

The following standards, test methods, and practices are referenced in this standard:

American National Standards Institute (ANSI)
American National Standards Institute, Inc., 11 West 42nd Street, 13th Floor, New York, NY 10036

ANSI/ASI S1.4-1983, *Specification for Sound Level Meters*

American Society of Mechanical Engineers (ASME)
American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990

BPVC-CC-N – 2004, Boiler and Pressure Vessel Code 04

American Society for Testing and Materials (ASTM)
American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

ASTM B 117 - 05, *Standard Practice for Operating Salt Spray (Fog) Apparatus*
ASTM D 412 - 98a(2002)e1, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers*
ASTM E – 1 - 05, *Standard Specification for ASTM Thermometers*
ASTM E1354-04a, S*tandard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*
ASTM G 36 – 94(2000), *Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution*
ASTM G 155 – 05a, *Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials*

Comité Européen des Assurances (CEA)
3 bis, rue de la Chaussée d'Antin – 75009, Paris, France

CEA 4008, *Fire Protection Systems - Specifications for Fire Extinguishing Systems Using Non-liquefied "Inert" Gases - Planning and Installation*, April 2005 (en).
CEA 4009, *Fire Protection Systems - Specifications for Fire Fighting Systems Using a Gaseous Extinguishant - Requirements and Test Methods for Selector Valves and Their Actuators*, February 2000 (en).
CEA 4012, *Fire Protection Systems - Specifications for Fire Fighting Systems Using a Gaseous Extinguishant - Requirements and Test Methods for Check and Non-return Devices*, February 2000 (en).
CEA 4013, *Fire Protection Systems - Specifications for Fire Fighting Systems Using a Gaseous Extinguishant - Requirements and Test Methods for Hoses and Container Connection Pipes*, February 2000 (en)
CEA 4014, *Fire Protection Systems - Specifications for Fire Fighting Systems Using a Gaseous Extinguishant - Requirements and Test Methods for Container and Valve Assemblies*, February 2000(en)
CEA 4016, *Fire Protection Systems - Specifications for Inert Gas Fire Fighting Systems: Requirements and Test Methods for Nozzles*, February 2000(en)
CEA 4045, *Fire Protection Systems - Specifications for Fire Extinguishing Systems Using Liquefied "Halocarbon" Gases - Planning and Installation*, April 2005 (en)

Compressed Gas Association (CGA)
Compressed Gas Association, 4221 Walney Road, Fifth Floor, Chantilly, VA 20151-2923

CGA G10.1, *Commodity Specification for Nitrogen*, Edition 6.
CGA S-1.1, *Pressure Relief Standards Part 1 - Cylinders for Compressed Gases*, Edition 12.

FM Approvals

1151 Boston-Providence Turnpike, P.O. Box 9102, Norwood MA 02062
http://www.fmglobal.com/approvals/resources/standards.asp

FM Approvals requirements for Class Number 3010, *Fire Alarm Control Equipment*
FM Approvals Standard Class Number 3600, *Electric Equipment for Use in Hazardous (Classified) Locations General Requirements*, November 1998.
FM Approvals Standard Class Number 3610, *Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, and Class I, Zone 0 and 1 Hazardous (Classified) Locations*, October 1999.
FM Approvals Standard Class Number 3611, *Nonincendive Electrical Equipment for Use in Class I and II, Division 2, and Class III, Divisions 1 and 2, Hazardous (Classified) Locations*, December 2004.
FM Approvals Approval Standard Class Number 3615, *Explosionproof Electrical Equipment General Requirements*, February 2006.
FM Approvals Approval Standard Class Number 3620, *Purged and Pressurized Electrical Equipment for Hazardous (Classified) Locations*, August 2000.
FM Approvals Approval Standard Class Number 3810, *Electrical and Electronic test, Measuring, and Process Control Equipment*, January 2005.
FM Approvals *Quality Assurance Guidelines for Manufacturers of FM Approved and Specification Tested Products*, September 2003.

FM Global

FM Global, 75 Remittance Drive, Suite 6182, Chicago, IL 60675-6182
http://www.fmglobal.com/fmglobalregistration

FM Global Property Loss Prevention Data Sheet 4-0, *Special Protection Systems*, April 2012.
FM Global Property Loss Prevention Data Sheet 4-9, *Clean Agent Fire Extinguishing Systems*, September 2010.

Institute of Electrical and Electronics Engineers (IEEE)

IEEE Standards Activities, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331

IEEE)/ASTM SI 10-2002*, American National Standard for Use of the International System of Units (SI): The Modern Metric System.*

International Organization for Standardization (ISO)

International Organization for Standardization, 1 rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland

ISO 14520-1: 2006, *Gaseous fire-extinguishing systems - Physical properties and system design*
ISO 17025 - 2005, *General Requirements for the Competence of Calibration and Testing Laboratories*

NFPA Publications

National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2004 Edition.
NFPA 72 - 2002, *National Fire Alarm Code*

National Institute of Standards and Technology (NIST)

NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070

NIST Technical Note 1278, *Preliminary Screening Procedures and Criteria for Replacements for Halons 1211 and 1301*

U.S. Department of Transportation (DOT)

Bureau of Explosives, 55500 DOT Road, Pueblo, CO 81001

Title 49, Code of Federal Regulations (CFR), *Hazardous Materials Regulations of the Department of Transportation*

1.9 Definitions

For the purposes of this standard, the following terms shall apply:

Accepted
Installations acceptable to the authority having jurisdiction and enforcing the applicable installation rules. When the authority is FM Global, such installations are termed "FM Global Accepted." Acceptance is based on an overall evaluation of the installation. Factors other than the use of FM Approved equipment impact on the decision to accept the equipment. Acceptance is not a characteristic of a product; acceptance is installation specific. A product accepted for one installation may not be acceptable elsewhere (contrast with the definition of FM Approval).

Actuation Device
A means of initiating clean agent fire extinguishing system discharge by opening the discharge valve.

Agent Storage Container
The assembly holding the clean agent supply for a fire extinguishing system. This includes the pressure vessel and various accessories necessary for management of the supply, such as valves, dip tubes, pressure gauges, and pressure relief devices.

Agent Storage Cylinder
See "Agent Storage Container"

Amplitude
The maximum displacement of sinusoidal motion from position of rest, or one-half the total table displacement, during a vibration test.

Area of Coverage
The maximum area that can be protected by a clean agent discharge nozzle or automatic extinguisher unit.

Authority Having Jurisdiction
The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

Automatic Control
An operating device, or arrangement of devices, which does not require human intervention. The automatic control includes a control panel that monitors fire detection devices and releases the agent when pre-established conditions have been met.

Automatic Extinguisher Unit
A clean agent extinguishing storage container that discharges following the operation of a heat responsive element. Automatic extinguisher units may also include optional mechanical manual controls. A single automatic extinguisher unit shall be used to protect each hazard area, unless it is possible to configure multiple units such that operation of any one will operate all others simultaneously.

Class A Fires
Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.

Class B Fires
Fires in ignitable liquids (also known as flammable or combustible liquids), petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.

Class C Fire
Fires that involve energized electrical equipment and during which the electric power is maintained, thereby continuously adding electrical energy.

Discharge Head

A removable portion of a discharge valve assembly that is required to be installed for system operation.

Discharge Nozzle

A device with one or more orifices that is connected to a termination of a pipe network for the purpose of controlling the discharge rate and uniformly distributing the extinguishing agent within a specific volume.

Discharge Time

The time interval between the first appearance of extinguishing agent at the discharge nozzle or unit and the time at which 95 percent of the agent has been discharged from the nozzle or unit.

Element Operating Temperature

The nominal temperature in degrees Fahrenheit (°F) or Celsius (°C) at which a heat responsive element operates when subjected to the influence of heat.

Engineered System

A clean agent fire extinguishing system designed using hydraulic calculations to predict mass flows and pressures at individual nozzles. These calculations analyze the entire piping system, taking into account variables such as friction loss in piping, nozzles, and other components.

Expellant Gas

The medium used to facilitate the discharge of the extinguishing agent from the agent storage container.

Flow Rate

The quantity of fluid passing through a nozzle or other device in a unit time. When a minimum discharge rate is indicated, reference is made to the minimum quantity of agent discharged per unit time, measured within ± 1 second.

FM Approvals Certification Marks

The FM Approvals Certification Marks are detailed in Appendix C, and their use is mandatory on all FM Approved systems. These registered marks cannot be used except as authorized by FM Approvals via the granting of Approval to a specific product. For clean agent extinguishing systems, the FM Approvals Certification Marks shall be placed on the system placard and not on individual components, unless those components have undergone a separate evaluation to the applicable standards.

FM Approved

Products certified by FM Approvals to the applicable FM Approval Standard(s). Such products are listed in the Approval Guide, an online resource of FM Approvals, or one of the supplements. All products listed in the Approval Guide have been successfully examined by FM Approvals, and their manufacturers have signed and returned a Master Agreement to FM Approvals. This contract obligates the manufacturer to allow re-examination of the product and surveillance audits at FM Approvals' discretion. It further requires the manufacturer not to deviate from the FM Approved configuration of the product without review by and agreement of FM Approvals. Approval is product specific.

Fully Mechanical Manual Control

A manual discharge control which can function in the absence of electric power or other energy sources other than stored system pressure.

Halocarbon Clean Agent

A gaseous fire extinguishant, electrically nonconducting and volatile, that does not leave a residue subsequent to evaporation. The material is delivered by a fire extinguishing system and acts to suppress or extinguish a fire, and includes as primary components one or more organic compounds containing the elements fluorine, chlorine, bromine, and iodine. Such an agent is more properly and more generally called a Vaporizing Liquid Clean Agent.

Heat Responsive Element

An operating device that does not require human intervention. This device includes an operating element that, when subjected to the influence of heat, ruptures, bursts, or otherwise functions, to cause the release of clean agent.

Inert Gas Clean Agent
A gaseous, electrically nonconducting fire extinguishant that does not leave a residue subsequent to evaporation. The material is delivered by a fire extinguishing system and acts to suppress or extinguish a fire, and includes as primary components one or more elemental gases such as helium, neon, argon, and nitrogen. Blends of inert gases may also contain carbon dioxide as a secondary component.

Lock-Out Valve
A supervised, lockable, manually operated valve located in the discharge line between the supply and the nozzles, which can be used to isolate the agent supply from all or part of the system during maintenance and service.

Manual Control
An operating device, or arrangement of devices that requires action by a human operator. The manual control may be initiated either mechanically or electrically.

Master Cylinder
One or more agent storage containers in a clean agent extinguishing system using multiple agent storage containers that are directly actuated by an operating device, then supply pressure to actuate one or more secondary cylinders.

Maximum Discharge Time
The longest allowable discharge time at 70°F (21°C) specified by the manufacturer. This time cannot be longer than 10 seconds for vaporizing liquid agents; for inert gas agents this time cannot exceed 120 seconds for the protection of Class A or Class C fire hazards, or 60 seconds for the protection of Class B fire hazards.

Maximum Working Pressure
The pressure in an agent storage container or other pressurized container, as applicable, associated with the maximum installation temperature.

Minimum Bending Radius
The smallest radius (expressed in inches [mm]) specified by the manufacturer to which a flexible hose is safely allowed to bend without damage.

Minimum Working Pressure
The pressure in an agent storage container or other pressurized container, as applicable, associated with the minimum installation temperature.

Operable Pressure Range
The minimum and maximum pressures of the agent storage container or other pressurized container, as applicable, over which the system is intended to be functional. These operating pressures result from the minimum and maximum storage temperatures and the physical characteristics of the agent and/or expellant gas, as applicable.

Operating Device
See “Actuation Device”

Operating Pressure
See “Operable Pressure Range”

Pilot Cylinder
A pressurized cylinder separate from the agent storage containers in a clean agent extinguishing system that is directly actuated by an operating device, then supplies pressure to actuate either a master cylinder, or one or more secondary cylinders.

Pre-Engineered System
A clean agent fire extinguishing system designed using a predetermined range of piping and nozzle characteristics and configurations to determine individual nozzle flow rates.

Proof Test Pressure

The factory test pressure used to verify the structural integrity of the agent storage container.

Resonance

The maximum magnification of applied vibration during a vibration test.

Secondary Cylinder

One or more cylinders in a clean agent fire extinguishing system using multiple agent storage containers that are operated by pressure supplied from a pilot or master cylinder, rather than directly by an operating device.

Selector Valve

A supervised valve normally operated automatically, but that also includes an emergency fully mechanical manual control, that can be used to restrict agent discharge to one of multiple zones protected by the same agent supply. Selector valves are controlled by the detection and control system and are used to avoid discharging the clean agent into a space in which no fire has yet been detected, even though the overall system has been actuated to protect one or more other spaces.

Specified

The value of a design parameter set by the manufacturer that shall be equal to, or more conservative than, the limiting values of this standard.

Supervised

A type of device, such as a valve, which is equipped with switches, or is otherwise electrically monitored, to allow its state to be displayed or to initiate an alarm via a control panel.

Total Flooding System

An extinguishing system designed to protect an enclosed hazard volume by discharging clean agent throughout the enclosed volume to reach and maintain an extinguishing concentration for the specific fuels for which it has been designed for a sufficient period of time to extinguish fires in those fuels.

Vaporizing Liquid Clean Agent

An electrically nonconducting, compressed liquid fire extinguishant that is vaporized at discharge and does not leave a residue subsequent to evaporation. The material is delivered by a fire extinguishing system and acts to suppress or extinguish a fire, and includes as primary components one or more organic compounds containing the elements fluorine, chlorine, bromine, and iodine.

Working Pressure

The pressure in a fully charged agent storage container or other pressurized container, as applicable, at 70° F (21° C).

Zone

A segment of a fire extinguishing system distribution piping supplied through a selector valve that delivers clean agent to one of the spaces protected by the system.

2. GENERAL INFORMATION

2.1 Approval Application Requirements

To apply for an Approval examination, the manufacturer, or its authorized representative, should submit a request to:

Fire Protection Group Manager
FM Approvals
Hydraulics Laboratory
743A Reynolds Road
West Glocester, Rhode Island 02814 U.S.A.

2.1.1 The manufacturer shall provide the following preliminary information with any request for Approval consideration:

- A complete list of all models, types, sizes, and options for the products being submitted for Approval consideration
- Assembly drawings, component drawings, materials list, anticipated marking format, nameplate format, brochures, sales literature, specification sheets, and design, installation, operation and maintenance instructions
- The number and location of manufacturing facilities

2.1.2 All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level.

2.1.3 All documents shall be provided with English translation.

2.1.4 The manufacturer may also be asked to complete an Application for FM Approval Services.

2.2 Requirements for Samples for Examination

2.2.1 Following authorization of an Approval examination, the manufacturer shall submit samples for examination and testing. Sample requirements are to be determined by FM Approvals following review of the preliminary information.

2.2.2 Sample requirements may vary depending on design features, results of prior testing, and results of any foregoing tests.

2.2.3 The manufacturer shall submit samples representative of production. Any decision to use data generated using prototype components or systems shall be at the sole discretion of FM Approvals.

2.2.4 The manufacturer shall be responsible for providing any necessary test fixtures that may be required to evaluate the system.

3. GENERAL REQUIREMENTS

3.1 Review of Documentation

During the initial investigation and prior to physical testing, the manufacturer's specifications, technical datasheets, and design details shall be reviewed to assess the ease and practicality of installation and use. The system and its components shall be suitable for use within the defined limits of the Approval investigation.

3.2 Physical or Structural Construction Features

3.2.1 Operating Range

All system components shall operate within the temperature ranges of Table 3.2.1. System and component evaluations will be based on the specified minimum and maximum operating temperatures. Operating temperatures outside these limits shall be specified at discrete 10ºF (5.6ºC) increments.

Table 3.2.1 *Required Operation Temperature Range*

Allowable Minimum Operating Temperature ***ºF (ºC)***	***Allowable Maximum Operating Temperature**** ***ºF (ºC)***
32°F (0°C), or lower	120°F (49°C), or higher

NOTE: Automatic extinguisher units only may specify a 100°F (37.8°C) maximum storage temperature.

3.2.2 Materials

3.2.2.1 All components shall be made of materials suitably corrosion resistant for their intended use.

3.2.2.2 Any seals used in the system shall be compatible with the clean extinguishing agent. Compatibility shall be determined by successful performance when subjected to the requirements listed in Sections 4.9.2 (Long Term Leakage Test), 4.9.3 (30-Day Maximum Temperature Leakage Test), 4.9.4 (30-Day Minimum Temperature Leakage Test), and 4.22 (Elastomeric Materials Tests).

3.2.3 Controls

3.2.3.1 For normal operation, a system shall be either automatically controlled or operable from a manual control, easily accessible to the hazard, or both. If the normal manual means of actuation incorporates electric power, the source of that power shall be completely independent of any electric power source used for automatic operation. A power source used for both normal manual and automatic operation shall be provided with an independent backup, such as a battery. All systems shall be provided with an alternate means of fully mechanical manual emergency control, regardless of their normal means of operation. Fully mechanical manual emergency controls shall not require an electric power source, but may make use of the clean agent extinguishing system's working pressure to operate the release. These emergency controls shall be located at or near the device being controlled.

3.2.3.2 Control panels shall comply with NFPA 72 and FM Approvals' Approval Standards Class Number 3010 and 3810. Control panels are not required to be submitted as a part of a system. However, system design shall be such that the system is operable by a minimum of one FM Approved detection and release panel that is compatible for use with the clean agent extinguishing system.

3.2.4 Pressure Vessels

3.2.4.1 Storage containers shall conform to the appropriate regulations for the installation location. In the U.S.A., DOT Title 49, CFR, Parts 171 through 180 are applicable for clean agent storage containers that are shipped under pressure.

3.2.4.2 In a system utilizing multiple storage containers, all containers supplying the same manifold shall be of the same size and design, allowing for interchangeability of position.

3.2.4.3 The following documents shall be submitted for each storage container design, to demonstrate compliance with the relevant design standard:

- Calculation of wall thicknesses per the method specified in the applicable standard, with appropriate supporting references as necessary
- Certificate of chemical analysis of materials
- Certificate of physical properties of materials

3.2.4.4 The pressurization level and the minimum and maximum filling densities shall be specified by the manufacturer for vaporizing liquid clean agents. The pressurization level and filling volume shall be specified by the manufacturer for inert gas agents.

3.2.5 Valves

If applicable, equivalent tube or pipe length of discharge valves shall be measured to allow accurate calculations for system design. Discharge valves shall incorporate varying sizes or connection designs for all ports to minimize the likelihood of improper connection during installation. Selector, check, and other valves not designed for mounting directly on a storage container may use inlet and outlet connections of the same size and design, but shall be marked to indicate correct direction of flow. For pressure operated valves, the manufacturer shall provide data for the minimum available force or torque for each actuator and the maximum required operating force or torque for the corresponding valve. Proper operation of the most adverse combinations shall be verified by test.

3.2.6 Gauges and Indicators

3.2.6.1 A pressure gauge shall be included with all extinguishing systems to indicate the pressure in the agent storage container, and shall comply with the following requirements:

- The face of the gauge shall indicate the appropriate units of pressure for which it is calibrated
- The range of the gauge shall be based on the system's operable pressure range
- The minimum indicated gauge pressure shall be marked on the left side of the gauge's range
- A 70°F (21ºC) value shall be marked at the system's working pressure
- The maximum gauge pressure shall be between 150 and 250 percent of the system working pressure at 70°F (21°C), and shall be marked on the right side of the gauge's range
- The gauge shall be provided with a means of pressure relief to allow venting in the event of an internal leak
- The face of the gauge shall identify the clean agent with which it is intended to be used

3.2.6.2 When the storage container cannot be easily weighed due to size or installation location, liquid level indicators or an alternative method of determining agent storage container fill level shall be provided for vaporizing liquid agents. When provided, liquid level indicators shall meet the requirements of Section 4.15.

3.2.7 Siphon Tubes

3.2.7.1 Systems containing a siphon tube to discharge the clean extinguishing agent from the storage container shall be configured so that the discharge end of the siphon tube is mechanically locked and sealed to remain in place during all conditions of use.

3.2.7.2 Vaporizing liquid clean agents are stored as liquids and superpressurized to the specified working pressure. Siphon tubes in these systems shall be designed to prevent gas discharge until the liquid level drops below the opening on the free end of the siphon tube.

3.2.7.3 The free end of the siphon tube shall be configured to prevent restriction of flow by contact with the cylinder wall. If the minimum clearance between the end of the siphon tube and the cylinder wall is less than 0.25 times the tube's inside diameter, equivalent length measurements for the system discharge valve shall be performed with the siphon tube in place and installed in the normal design proximity to the cylinder wall. Compliance with this requirement shall be demonstrated by drawings showing the calculated assembly clearance, based on worst case dimensional tolerance stack-ups. Alternatively, the manufacturer's assembly process may contain controlled procedures for verifying the minimum required clearance.

3.2.8 Pressure Relief Devices

Calculations shall be submitted to verify that the pressure relief device is designed to comply with the flow capacity and operating pressure requirements specified in CGA S-1.1, or equivalent regulations acceptable to the authority having jurisdiction. The construction and size of the pressure relief device shall, at a minimum, be appropriate for the system pressure at the maximum specified operating temperature.

3.2.9 Anti-Recoil Devices

The discharge valve outlet of an agent storage container shall be provided with an anti-recoil device for the purpose of shipping, handling, and storage. The device shall be an integral part of or attached to the container via a chain, or otherwise designed to minimize the likelihood of removal from the container.

3.2.10 Discharge Heads and Connectors

If a system discharge head must be removed from the valve assembly during weighing or recharging operations, the assembly shall contain a check valve. When a flexible loop connector must be removed, a plug or cap shall be provided to seal the disconnected end of the loop. Appropriate warnings shall be displayed on these devices to caution the user with regard to the high pressure discharge hazard and the proper procedure for mitigating this hazard.

3.2.11 Manifolds and Piping

Manifolds of proprietary designs used in place of standard pipe and fittings shall have minimum internal diameters greater than or equal to that of the corresponding pipe sizes. In multiple container installations where the discharge of a pilot cylinder(s) actuates secondary cylinders, the manifold piping shall be arranged so that any one pilot cylinder will actuate the remaining cylinders, regardless of the total number of pilot cylinders in the system. All cylinders in a manifold arrangement shall be of the same size and design.

3.2.12 Cylinder Supports

Equipment which supports multiple cylinder installations shall be designed to facilitate the removal of individual cylinders for inspection and servicing.

3.2.13 Protective Covering

All valves and control devices with exterior movable parts that are vulnerable to obstruction or physical damage shall be protected by paneled enclosures or cages. Operating, levers, handles, or buttons requiring manual access for operation shall be exempt from this requirement to the extent necessary to allow for their unimpeded operation. Conduit shall be used for electrical cables and wires, or pressurized tubes outside the enclosures. Tubing used for heat detection may be exposed in the areas being monitored, but shall be enclosed where not performing this function and vulnerable to mechanical damage. Mechanical cables shall be sheathed or otherwise protected to minimize the likelihood of damage or mechanical interference with operation.

3.2.14 Actuation Devices

3.2.14.1 The device which opens a cylinder discharge valve shall either be an independent actuation device attached to the valve, or an internal component of either the discharge head or the valve assembly itself.

3.2.14.2 One action shall actuate all the cylinders in a manifold arrangement. This shall be accomplished automatically by the connection of pilot to secondary cylinders, or by a mechanical system acting simultaneously on all cylinder valves. In the former arrangement, pressure from a pilot cylinder acts through some mechanism in the secondary cylinder actuation device, valve assembly, or discharge head to unseat the valve disk and open the valve. Such pistons shall have sufficient area such that, when acted upon by the minimum pilot pressure, sufficient force is generated to overcome the force generated by the maximum system pressure acting over the valve disk sealing area. Compliance shall be demonstrated by testing or by the submission of appropriately annotated drawings displaying the area ratio calculation. Mechanical systems shall be configured to provide sufficient force to operate secondary cylinders pressurized to the maximum system pressure when actuated by the minimum available force.

3.2.14.3 Actuation devices on pilot cylinders shall be designed for single or simultaneous multiple unit operation. They shall be actuated automatically by a compatible Approved detection and control system, or by a fully manual emergency release device. Handles or levers on manual controls shall not require a force to operate exceeding 40 lb (178 N), a travel distance of more than 14 in. (355 mm), or a rotation of more than 270 degrees.

3.2.14.4 Electric actuation devices shall be designed with a provision for remote supervision of installation onto the valve or device they control, or operability for actuators integrated into the discharge valve (remote supervision of electric actuation devices required by January 1, 2016).

3.2.15 Auxiliary Manual Controls

Auxiliary manual controls shall be provided for systems using automatic-only actuation devices or mechanical release devices that do not incorporate a fully mechanical manual control. These auxiliary controls shall be used for remote, manual operation or in emergencies due to failure of the automatic control. Auxiliary manual controls that are not located within the protective enclosures provided for other components shall be protected against accidental operation by a suitable enclosure or other means. Corner pulleys shall be provided for smooth operation of control devices that require cables.

3.2.16 Selector and Lockout Valves

The equivalent length of selector and lockout valves shall be measured to allow accurate calculations for system design. The actuation of one selector valve shall not open other selector valves in the system. Lockout valves shall be designed with a provision for remote supervision of valve position (fully open or fully closed). Selector valves shall be designed with a provision for remote supervision of electric actuation device installation, or operability for actuators integrated into the valve (remote supervision of electric actuation devices required by January 1, 2016). Lockout valves are not normally required for clean agent extinguishing systems. However, lockout valves may be required when design concentrations are above the No Observable Adverse Effect Level (NOAEL) for occupied spaces. Supervisory devices shall be compatible with the appropriate FM Approved control equipment.

3.2.17 Nozzles

Discharge nozzles shall be evaluated for the intended use, including flow characteristics and area of coverage. Nozzles or outlets shall be made of metallic, corrosion resistant materials that will not deform or otherwise be damaged by fire exposure or discharge pressure. Nozzles shall be permanently marked with their part number. When the part number alone does not identify orifice size, the orifice size shall also be permanently marked on the nozzle.

3.2.18 Nozzle Caps or Frangible Seals

Caps or frangible seals shall be provided on nozzles for installations in which the nozzles are subject to clogging from external materials. Such caps or seals shall have a maximum releasing pressure of 44 psi (3 bar) as installed, and shall not obstruct flow from the outlet subsequent to release.

3.2.19 Clean Agents

Vaporizing liquid and inert gas clean extinguishing agents for use in fire extinguishing systems shall be recognized under the United States Environmental Protection Agency's Significant New Alternatives Program, and shall meet the requirements of NFPA 2001 or the equivalent local standard(s) acceptable to the authority having jurisdiction, and shall either be FM Approved as a clean agent system component or shall be examined for the system manufacturer to the same extent as an agent submitted for component Approval. All agent storage containers shall be filled at an FM Approved location, which is included in the FM Approvals' Surveillance Audit Program.

3.2.20 Expellant Gases

Nitrogen used in a clean agent system shall have a dew point of no greater than -60°F (-51.1°C), and shall be grade H, I, J, K, L, M, N, O, or P, as described in Table 1 of *Commodity Specification for Nitrogen*, CGA G-10.1. The use of any other expellant gas shall be evaluated at the discretion of FM Approvals.

3.2.21 Auxiliary Equipment

Auxiliary equipment includes those devices required in a system to protect against a specific hazard. The need for these devices shall be determined by FM Approvals according to the nature of the hazard. The devices listed below may be required for the system to attain Approval for specific applications. Other devices not included below may also be required.

3.2.21.1 Pressure Operated Release

A pressure operated release shall be provided on all doors and windows in a hazard area which is to be sealed off in the event of fire. The release shall operate at a maximum pressure of 40 psi (2.8 bar) from a piston or plunger driven by clean agent from the extinguishing system. The release shall not permit the escape of excessive gas from the system. It shall automatically reset and may have a control for manual operation.

3.2.21.2 Pressure Operated Switches

Pressure operated switches may be used to shut down fans, conveyors, or other electrical equipment in or near the hazard area, as well as to activate alarm and indicator circuits. These switches shall not require a pressure of more than 40 psi (2.8 bar) to operate, and shall not release excessive gas from the system. They may also have an alternate manual control, and shall be designed for manual resetting only.

3.2.21.3 Time Delays

A delay device may be installed on systems when the evacuation of personnel from the hazard area prior to system discharge is required. This device may allow discharge to be aborted or immediately initiated through a manual override during the delay period. The duration of delay is a function of both the specific clean agent used and the design concentration, and is determined by the authority having jurisdiction.

3.2.21.4 Alarms

Alarms and/or indicators shall be provided to show that the system is operating, warn personnel of the forthcoming discharge of clean agent or of its presence in unventilated areas, and signal the failure of any supervised equipment. Indicators that show the system has been used and requires service shall operate following actuation of the system and require manual resetting. When pneumatically operated alarms are powered by a vaporizing liquid clean agent, the discharge of agent from the device shall be piped outside of the protected area to minimize potentially damaging products of decomposition prior to system operation.

3.2.21.5 Check Valves

Check valves shall be provided in the manifold piping on system installations incorporating multiple storage containers. They shall open at a maximum pressure of 0.1 times the system pressure at maximum storage temperature.

3.2.21.6 Venting Valves

Devices shall be provided to prevent the premature operation of discharge or selector valves by residual pressures that may leak into enclosed manifolds, actuation devices, or discharge heads. They shall have closing pressures of 25 to 100 psi (1.7 to 6.9 bar). If these vents are incorporated in actuation devices, they shall be closed when the control is in operation and open when the control is inoperative.

3.2.21.7 Changeover Devices

Changeover devices, such as valve or switch assemblies, shall be provided on automatic systems having both primary and connected reserve agent storage containers. This will direct the command of the automatic fire detection device to the proper series of containers. The changeover device shall be suitably protected and labeled and shall indicate which containers are subject to operation.

3.2.22 Hazardous Location Rating of Components

Components designed for use in hazardous locations shall be FM Approved only if successfully evaluated for compliance to the relevant requirements of one or more of the following FM Approvals Standards:

Table 3.2.22 *Hazardous Location Electrical Equipment Standards*

FM Approvals Class Number	***Standard Title***
3600	Electric Equipment for use in Hazardous (Classified) Locations General Requirements
3610	Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, & III, Division 1,and Class I, Zone 0 & 1 Hazardous (Classified) Locations
3611	Nonincendive Electrical Equipment for Use in Class I and II, Division 2, and Class III, Divisions 1 and 2, Hazardous (Classified) Locations
3615	Explosionproof Electrical Equipment General Requirements
3620	Purged and Pressurized Electrical Equipment for Hazardous (Classified) Locations
3810	Electrical and Electronic Test, Measuring, and Process Control Equipment

3.3 Markings

3.3.1 Easily visible nameplates shall be affixed to the agent storage container assembly of clean agent extinguishing systems, and shall display the following markings at a minimum. Any additional markings required by the authority having jurisdiction shall also be provided:

- Manufacturer's name and address
- System type and model number
- The FM Approvals Certification Mark, (Appendix C)
- Clean agent identification
- System working pressure
- Allowable ambient storage temperature range
- Factory test pressure of storage container
- Year of manufacture of the storage container (if not directly stamped on the container)
- Reference to NFPA 2001, *Standard for Clean Agent Extinguishing Systems*, and/or any other relevant local standards
- Reference to the manufacturer’s design, installation, operation, recharge, and maintenance instructions
- Weight of agent charge and total container weight

3.3.2 Combination instruction and identification plates shall be mounted on or next to all control devices. All significant components or assemblies shall also individually bear an identification mark, such as a part, catalog, or pattern number.

3.3.4 All marking plates shall be made of materials which will not corrode or otherwise become illegible due to system liquids or vapors, or normal environmental conditions.

3.3.5 When hazard warnings are required by the authority having jurisdiction, the markings should conform to the authority’s requirements and if possible, be universally recognizable.

3.3.6 The system’s model or type identification shall correspond to the manufacturer's catalog designation and shall uniquely identify the product as FM Approved. The manufacturer shall not place this model or type identification on any other product unless covered by a separate agreement with FM Approvals.

3.3.7 The FM Approvals Certification Mark (Appendix C) shall be displayed visibly and permanently on the product and/or packaging, as appropriate. The manufacturer shall not use this mark on any other product unless covered by separate agreement with FM Approvals.

3.3.8 All markings shall be legible and durable.

3.4 Manufacturer's Design, Installation, Operation, and Maintenance Instructions

3.4.1 The manufacturer shall provide information required to properly design, install, operate, and maintain the system. These instructions shall be submitted to FM Approvals prior to the examination of a system.

3.4.2 The manufacturer shall provide guidance for the design or evaluation of protected enclosures to ensure that the pressurization caused by system design will not damage the enclosure. Such guidance shall include consideration of the minimum enclosure strength, required leakage area, and proper vent sizing requirements. For inert gas clean agents, enclosure pressurization calculations shall incorporate a discharge time 10 seconds less than that calculated in the system design to account for the allowable tolerance in the Verification of Flow Calculation Method Test of Section 4.6. For all systems, enclosure pressurization calculations shall be based upon maximum fill density agent storage containers at the manufacturer's maximum specified installation temperature.

3.4.3 The manufacturer's design instructions for a system submitted for FM Approval shall be evaluated based on FM Global requirements, NFPA 2001, and any other relevant standards required by the local authority having jurisdiction.

3.5 Calibration

All equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage of the equipment. For testing conducted at locations other than FM Approvals, a copy of the calibration certificate for each piece of test equipment that indicates the calibration was performed to standards traceable to the National Institute of Standards and Technology (NIST), or to other acceptable reference standards by an accredited ISO 17025 calibration laboratory, is required. The test equipment must be clearly marked with identification, including the last date of the calibration and the next due date. In addition, a copy of the ISO 17025 accreditation certificate for the calibration laboratory is required for FM Approvals records.

The calibration of recently purchased new equipment is also required. Documentation indicating either the date of purchase or date of shipment, equipment description, model and serial number is required for identification. The period from the time the equipment was put into service to the date of testing must be within an interval that does not require the equipment to be calibrated as determined on the basis of the parameters mentioned above.

3.6 Tolerances

Tolerances on units of measure shall be as described in Appendix B, unless otherwise specified.

4. PERFORMANCE REQUIREMENTS

4.1 Class A and B Fire Extinguishment Tests

4.1.1 Requirement

4.1.1.1 Class A Fire Extinguishment Tests

Clean agent extinguishing systems shall successfully extinguish each Class A fire within 600 seconds after the end of system discharge. For the purposes of these tests, the end of discharge shall be considered to be at the maximum discharge time. Following a 600 second soak period, there shall be no signs of re-ignition of the materials defined in Sections 4.1.2.1.A and 4.1.2.1.B. For the polymeric material tests, the weight loss of each sample between 10 seconds and 600 seconds after the end of discharge shall not exceed 15 grams. This test is used to confirm the minimum extinguishing concentration (MEC) for a clean agent on Class A combustible materials.

4.1.1.2 Class B Fire Extinguishment Tests

Clean agent extinguishing systems shall successfully extinguish each Class B fire within 30 seconds after the end of system discharge. For the purposes of these tests, the end of discharge shall be considered to be at the maximum discharge time. This test is used to confirm the minimum extinguishing concentration for a clean agent on Class B ignitable liquids (also known as flammable or combustible liquids). While certain Class B hazards may have MECs (cup burner values per NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, Annex B), FM Approved systems must use at least the MEC defined in these tests for all Class B hazards.

4.1.2 Tests/Verification

The test enclosure shall be constructed of plywood with a minimum thickness of 3/8 inch (9.5 mm), or an equivalent material. The enclosure shall contain a minimum volume of 3531 ft^3 (100 m^3), with a minimum ceiling height of 11.5 ft (3.5 m), and each wall shall be a minimum of 13.1 ft (4 m) long. Openings shall be provided for the purpose of venting prior to system discharge. Additionally, a pressure relief opening shall be provided in the top of the enclosure. Provisions for visual observations of the interior of the enclosure shall be provided. Prior to each fire test, the enclosure shall be maintained at 70°F ± 5°F (21°C ± 3°C).

Each test shall include a piping configuration and discharge nozzle resulting in the minimum specified nozzle design pressure at 70°F (21°C).

When a clean agent is being evaluated for component Approval and not a part of a system Approval, the highest nozzle pressure used in the component Approval fire tests shall define the minimum nozzle pressure that can be used with that clean agent in any system Approvals.

The agent storage container shall be conditioned to 70°F ± 5°F (21°C ± 3°C), and maintained at this temperature for the duration of each fire test.

The clean agent concentration used in each fire test shall be determined by dividing the specified design concentration at an ambient temperature of 70°F (21°C) by 1.2 for Class A materials or 1.3 for Class B materials, and shall be calculated for each test using the appropriate formula, as follows:

For vaporizing liquid clean agents:

$$W = \left[\frac{V}{s}\right] \times \left[\frac{C}{100 - C}\right]$$

For inert gas clean agents:

$$W = \left[\frac{V}{s}\right] \times \ln\left[\frac{100}{100 - C}\right]$$

Where:

W = Agent quantity [lb or kg*]
V = Volume of the test enclosure [ft^3 or m^3*]
s = Specific volume of clean agent at test temperature T [ft^3/lb or m^3/kg*]
T = Test enclosure temperature after the design concentration has been achieved in the enclosure
C = Agent volume concentration [percent]

*These equations work for either U.S. customary or SI units as long as units of one type are used consistently throughout the calculation.

Further information regarding the specific volume of various clean extinguishing agents is located in NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*.

Where barometric pressure deviates from the normal sea-level value of 29.92 inHg (760 mmHg) by more than 5 percent, the required weight of agent shall be adjusted by multiplying the weight calculated from the formula above by the ratio [barometer actual/barometer norm] to address the corresponding differences in oxygen concentration in the test enclosure.

4.1.2.1 Class A Fire Extinguishment Tests

A. Wood Crib

The crib shall be constructed of four layers of six 1-1/2 x 1-1/2 x 18 in. long (3.8 x 3.8 x 460 mm long) wood members. The wood shall be kiln dried spruce or fur lumber having a moisture content between 9 and 13 percent. Within each layer, the wood members shall be evenly spaced to form an 18 in. x 18 in. (460 mm x 460 mm) square. The members of successive layers shall be positioned at right angles to those of the adjacent layer. The outside edge of the outer members of each layer shall be placed flush with the ends of the members of each adjacent layer. The wood members shall be stapled or nailed together at the outside edges of the crib.

The test enclosure shall include provisions for oxygen concentration measurements. The measurements shall be taken using a calibrated instrument, and shall be recorded at the following locations:

- At the height of the bottom of the wood crib, centered from the edge of the wood crib to the wall
- At 0.1 H, where H is the height of the test enclosure, centered from the edge of the wood crib to the wall
- At 0.9 H, where H is the height of the test enclosure, centered from the edge of the wood crib to the wall

A 2.5 ft^2 (0.23 m^2) square steel pan, a minimum of 4 in. (100 mm) in height, shall be placed on the floor of the enclosure, centered below the wood crib, with a distance of 12 in. (305 mm) between the bottom of the crib and the top of the pan. The test stand shall be constructed so that the bottom surface of the wood crib is exposed to the atmosphere. The square pan shall be filled with a sufficient quantity of heptane, as defined in Table 4.1.2.2, to provide a minimum of 3 minutes of burning. The heptane shall be ignited, and the crib shall be allowed to burn freely outside of the test enclosure for 6 minutes. Alternatively, pre-burn of the heptane and crib may occur within the enclosure if adequate ventilation provisions are provided. Ventilation shall ensure that the oxygen content within the enclosure, measured below the wood crib, is not reduced by more than 0.5 volume percent below ambient prior to system discharge.

Fifteen seconds prior to the end of the 6 minute pre-burn period, the wood crib shall be moved into the test enclosure, and placed on a stand so that the bottom of the crib is 24 in. to 30 in. (610 mm to 760 mm) above the floor of the test enclosure. The crib shall be positioned in the test enclosure prior to the completion of the pre-burn period. The vents shall be closed, and the system discharged. The oxygen concentration at the bottom of the crib at the time of discharge shall be within 0.5 volume percent of normal atmospheric conditions of approximately 21 volume percent.

Observations shall be made for extinguishment of the crib fire and the time of extinguishment and shall be recorded. Following discharge, the test enclosure shall remain sealed for 600 seconds. The crib shall then be removed from the enclosure, and observations of the crib shall be made for signs of reignition.

The wood crib fire test shall be performed three times; three successful tests shall be required.

B. Polymeric Materials

The tests shall be conducted using polymethyl methacrylate (PMMA), polypropylene (PP), and acrylonitrile-butadiene-styrene polymer (ABS), characterized by the properties of Table 4.1.2.1.B. Certifications of material properties shall be supplied by the manufacturer for FM Approvals review. The certifications may be provided by the material manufacturer or an independent laboratory qualified to perform the required tests. Laboratory qualifications to be reviewed shall include proof of calibration of the test equipment used, including ISO 17025 certification of the calibrator.

Table 4.1.2.1.B *Polymeric Materials Properties**

Fuel	*Color*	*Density* g/cm^2	*Ignition Time*		*180 Second Average Heat Release Rate*		*Effective Heat of Combustion*	
			Value sec	*Tolerance* percent	*Value* kW/m^2	*Tolerance* percent	*Value* MJ/kg	*Tolerance* percent
PMMA	Black	1.19	77	± 30	286	± 25	23.3	± 15
PP	Natural (White)	0.905	91	± 30	225	± 25	39.8	± 15
ABS	Natural (Cream)	1.04	115	± 30	484	± 25	29.1	± 15

* 25 kW/m^2 exposure in cone calorimeter per ASTM E 1354-04a.

Each polymeric fuel array shall be constructed with four sheets of 3/8 in. (9.5 mm) thick by 16 in. (405 mm) tall by 8 in. (205 mm) wide. The sheets shall be fixed 8 in. (205 mm) above the floor of the test enclosure, at the spacing specified in Figures E-1 through E-4.

A 15 in. (380 mm) wide by 33.5 in. (850 mm) high by 24 in. (610 mm) deep fuel shield, as shown in Figures E-1 and E-2, shall be placed around two sides and at the top of the fuel array. The shield shall be constructed with a metal frame. The 24 in. (610 mm) wide by 33.5 in. (850 mm) high sides and the 24 in. (610 mm) by 15 in. (380 mm) top shall be fabricated from sheet steel. The remaining two sides and the bottom of the fuel array shall not be covered by the fuel shield. The fuel array shall be positioned such that the 8 in. (200 mm) sides of the polymeric sheets are parallel to the 24 in. (610 mm) side of the shield.

Two square baffles shall be placed around the exterior of the fuel shield, as shown in Figure E-5. Each baffle shall measure 37.5 in. (950 mm) on a side and 12 in. (300 mm) tall. One baffle shall be placed at a distance of 3.5 in. (90 mm) above the test enclosure floor. The second baffle shall be placed on top of the other and rotated 45 degrees with respect to the bottom baffle.

The test enclosure shall include provisions for oxygen concentration measurements. The measurements shall be recorded at the following locations:

- At the height of the bottom of the fuel array, centered from the edge of the array to the nearest wall of the enclosure
- At 0.1 H, where H is the height of the test enclosure, centered from the edge of the array to the nearest wall of the enclosure
- At 0.9 H, where H is the height of the test enclosure, centered from the edge of the array to the nearest wall of the enclosure

A 2 in. (50 mm) by 2 in. (50 mm) by 0.875 in. (22 mm) deep steel pan shall be centered below the fuel array, with a distance of 0.5 in. (13 mm) between the bottom of the array and the top of the pan. The square pan shall be filled with a sufficient quantity of heptane meeting the requirements specified in Table 4.1.2.2 to provide a minimum of 90 seconds of burning. The heptane shall be ignited and burn freely for 90 seconds.

210 seconds after ignition of the heptane, the vents shall be closed, and the system discharged. The oxygen concentration in the enclosure at the time of discharge, measured at the level of the fuel array, shall be within 0.5 volume percent of atmospheric conditions.

Observations shall be made for extinguishment of the polymeric fuel array. Following discharge, the test enclosure shall remain sealed for 600 seconds. The array shall then be removed from the enclosure, and observations of the array shall be made for signs of reignition.

The following data shall be recorded using an automated data acquisition system throughout the duration of the fire test:

- Oxygen concentration
- Instantaneous fuel mass

The following events shall be recorded:

- Time of heptane ignition
- Time of polymeric fuel array ignition
- Time of system discharge
- Time of end of discharge
- Time of visible fire extinguishment

The fire test shall be performed three times with each polymeric material; three successful tests shall be required for each material.

4.1.2.2 Class B Fire Extinguishment Tests

A minimum size 2.5 ft^2 (0.23 m^2) square steel pan shall be used. It shall be constructed from steel at least 1/4 in. (6.4 mm) thick, with the joints welded and liquid tight. A 1.5 in. (38 mm) by 1.5 in. (38 mm) by 3/16 in. (5 mm) thick reinforcing angle, forming a 1.75 in. (44 mm) wide turned out edge that is flush with the top edge of the pan, shall be provided along the perimeter of the pan. The reinforcing angle shall be continuously welded to the outside of the pan at the top edge, and tack welded at the edge of the lower leg of the angle. The top of the pan shall be 26 in. - 30 in. (660 mm - 760 mm) above the test enclosure floor. If Approval for extinguishment of pool fires larger than 2.5 ft^2 (0.23 m^2) is requested, then the test fire size shall be appropriately increased.

The test enclosure shall include provisions for oxygen concentration measurements. The measurements shall be taken using a calibrated instrument, and shall be recorded at the following locations:

- At the height of the top of the steel pan, centered from the edge of the pan to the nearest wall of the enclosure
- At 0.1 H, where H is the height of the test enclosure, centered from the edge of the pan to the nearest wall of the enclosure
- At 0.5 H, where H is the height of the test enclosure, centered from the edge of the pan to the nearest wall of the enclosure

The steel pan shall be filled with a minimum of 2 in. (50 mm) of heptane meeting the requirements specified in Table 4.1.2.2, and centered in the test enclosure. The heptane level shall be a minimum of 2 in. (50 mm) below the top of the pan. The heptane shall exhibit the properties specified in Table 4.1.2.2.

Table 4.1.2.2 *Required Heptane Characteristics*

Characteristic	***Required Value***
Maximum Initial Boiling Point	190°F (88°C)
Maximum Dry Point	212°F (100°C)
Specific Gravity at 60°F (15.6°C)	0.67 – 0.73

The heptane shall be ignited and allowed to burn freely for 30 seconds. The vents shall be closed, and the system discharged. The oxygen concentration in the enclosure at the time of discharge shall be within 0.5 units of atmospheric conditions. Observations shall be made for extinguishment of the heptane fire.

The heptane fire test shall be performed three times; three successful tests shall be required.

4.1.3 Verification of Fire Extinguishment Test Concentration

4.1.3.1 Requirement

The test enclosure shall be sufficiently tight to ensure that the weight of agent supplied results in achievement of the intended concentration.

4.1.3.2 Test/Verification

For a minimum of one of the fire extinguishment tests, the scenario shall be repeated with no fire present. The enclosure volume shall be monitored by means of oxygen concentration meters, as specified in Section 4.1.2.2. One minute after the end of discharge, the oxygen concentration shall be reduced to a level no less than that corresponding to the agent concentration used in the appropriate equation from Section 4.1.2. The actual agent concentration shall be calculated per the following equation:

$$C_a = 100 \times \left(1 - \frac{O_{2(f)}}{O_{2(s)}}\right)$$

Where:

C_a is the actual extinguishing concentration achieved (volume percent),
$O_{2(f)}$ is the final average volume percent oxygen concentration in the enclosure after 1 minute, and
$O_{2(s)}$ is the starting volume percent oxygen concentration in the enclosure.

4.2 Nozzle Distribution Verification Tests

4.2.1 Requirement

Engineered and pre-engineered clean agent extinguishing systems and automatic extinguisher units shall successfully achieve the extinguishing concentration throughout the enclosure within 30 seconds after the end of system discharge. For vaporizing liquid systems only, where the discharge time at the minimum specified operating temperature exceeds 30 seconds, the extinguishing concentration shall be achieved within 60 seconds after the start of system discharge.

4.2.2 Tests/Verification

The test enclosure shall be constructed of plywood with a minimum thickness of 3/8 inch (9.5 mm), or an equivalent material. Openings in the enclosure shall be provided for the purpose of venting prior to system discharge. Additionally, a pressure relief opening shall be provided in the top of the enclosure. Provisions for visual observations of the interior of the enclosure shall be provided. Prior to each fire test, the enclosure shall be maintained at 70°F ± 5°F (21°C ± 3°C).

The enclosure volume shall be constructed based on the minimum protected height limitation specified by the manufacturer and the maximum area of coverage for the system or nozzle being tested. A second enclosure shall be constructed based on the maximum protected height limitation specified by the manufacturer. For pre-engineered and engineered extinguishing systems, this second enclosure shall be a minimum of 13.1 ft (4 m) wide by 13.1 ft (4 m) long, and include a volume of a minimum of 3531 ft^3 (100 m^3). For automatic extinguisher units, the second enclosure shall include the maximum specified protected volume for the unit. Systems designed to protect smaller spaces only shall be tested in the manufacturer's specified maximum volume enclosure, and their Approval shall state this limitation.

The enclosure's footprint shall be rectangular. It shall contain a vertical baffle, and the baffle shall extend the full height of the enclosure. If the nozzle is centered in the enclosure or on one of the walls, the baffle shall be parallel to two of the walls and its width shall be 20 percent of the width of the walls to which it is parallel. It shall be centered on the centerline of the nozzle, perpendicular to the nozzle discharge, and located halfway between the nozzle and the far wall. If the enclosure's footprint is not square, separate tests shall be conducted with appropriate width baffles parallel to both the long and short walls. See Figure E-6. If the nozzle is not centered in the enclosure or on one of the walls, the baffle shall be centered on the centerline of the nozzle, perpendicular to the nozzle discharge, and located halfway between nozzle and the farthest corner of the enclosure. In these cases, the baffle width shall be 20 percent of the width of the largest enclosure cross section to which it is parallel.

Agent concentration shall be measured by appropriately selected and calibrated oxygen or other gas analyzers. Continuous data logging of the gas analyzer readings is required for a minimum of 195 seconds from discharge initiation for inert gases, or 85 seconds from discharge initiation for vaporizing liquids. Manual data collection shall not be acceptable. Ten sampling locations shall be located as follows:

- One point within 2 in. (50 mm) of each wall at each corner of the enclosure, located vertically within 12 in. (300 mm) of the top or bottom of the enclosure (eight total)
- Two points centered on the opposite side of the baffle from the nozzle: one at mid height and one within 12 in. (300 mm) of the floor of the enclosure
- For enclosure heights less than 3 ft (1 m), only one level of sampling points is required (five total).

Each sampling location shall reach the required concentration within 30 seconds after the end of discharge, or within 60 seconds after the start of system discharge for vaporizing liquid systems where the discharge time at the minimum specified operating temperature exceeds 30 seconds. Fluctuating readings may need to be smoothed using a moving average over the period after the end of discharge at the discretion of FM Approvals.

Alternatively, telltale heptane can fires may be used to verify agent concentration in place of gas analyzers. For this method, steel test cans, having a maximum nominal thickness of 0.216 in., 3.0 to 3.5 in. (76 to 89 mm) in diameter, and at least 4 in. (102 mm) tall, shall be placed in the sampling locations described above. These cans shall be filled

with a minimum of 2 in. of heptane meeting the requirements specified in Table 4.1.2.2, to a level a minimum of 2 in. below the top of the can. Provisions must be made to monitor each can for extinguishment. The heptane shall be ignited and allowed to burn freely for 30 seconds with the enclosure door and/or vents open. The vents shall be closed, and the system discharged. Each can shall be extinguished within 30 seconds after the end of discharge.

The test configuration shall be designed to evaluate the most adverse specified configurations of the extinguishing system with respect to the following:

- All configurations of discharge nozzle(s), including both 360º, sidewall, and corner versions, as well as any deflectors or other ancillary devices used with the discharge nozzle(s)
- Maximum area of coverage of discharge nozzle(s)
- Minimum system operating temperature
- Location of the extinguisher unit or discharge nozzle(s) in the protected volume
- For pre-engineered systems, the maximum piping and discharge nozzle limitations, including the most conservative piping configuration, length of pipe, number of fittings, and discharge nozzle configuration
- For engineered systems, the piping and discharge nozzle configuration resulting in 90 percent of the minimum nozzle design pressure at 70°F (21°C)
- For automatic extinguisher units, the maximum protected enclosure volume
- Agent storage container fill density which results in the lowest discharge nozzle pressure
- Maximum discharge time, ± 1 second for vaporizing liquids or ± 10 seconds for inert gases
- Most adverse combinations of interdependent parameters, such as maximum height and maximum discharge time or maximum area and minimum discharge time. The necessity of evaluating such combinations shall be subject to the judgment of FM Approvals in consultation with the manufacturer and, if necessary, verified by exploratory testing

The clean agent concentration used in each test shall be equal to the specified design concentration at an ambient temperature of 70°F (21°C) divided by 1.3, and shall be calculated for each test using the formula shown in Section 4.1.2.

4.2.2.1 Minimum Room Height/Maximum Nozzle Area of Coverage Test

Tests shall be conducted with all nozzle configurations, and as described in Section 4.2.2.

4.2.2.2 Maximum Room Height Test

A. Tests shall be conducted with all nozzle configurations, within the appropriate enclosure, and as described in Section 4.2.2.

B. The baffle shall be removed from the enclosure, and a 2.5 ft^2 (0.23 m^2) square steel pan shall be centered in the test enclosure. The pan shall be as described in Section 4.1.2.2. The top of the pan shall be 26 - 30 in. (660 - 760 mm) above the test enclosure floor. For systems designed to protect smaller spaces being tested in the manufacturer's specified maximum volume enclosure, the pan size may be scaled down, but the pan area must be a minimum of 1.45 percent of the enclosure's footprint area.

The steel pan shall be filled with a minimum of 2 in. (50 mm) of heptane meeting the requirements specified in Section 4.1.2.2. The heptane level shall be a minimum of 2 in. (50 mm) below the top of the pan. The heptane shall be ignited and allowed to burn freely for 30 seconds with the enclosure door and vents open. The vents shall be closed, and the system discharged. Observations shall be made for extinguishment of the heptane fire.

4.2.2.3 Automatic Extinguisher Unit Automatic Operation Fire Tests

For automatic extinguisher units, the tests described in Sections 4.2.2.1 (Minimum Room Height/Maximum Nozzle Area of Coverage Test) and 4.2.2.2 (Maximum Room Height Test) shall be supplemented by a minimum of two of the automatic operating extinguishment tests described below. These tests shall be conducted at the design concentration, rather than the minimum extinguishing concentration, and in the maximum room height test enclosure, which shall include the maximum specified protected volume for the unit.

A 2.5 ft^2 (0.23 m^2) square steel pan, as described in Section 4.1.2.2, shall be centered in the test enclosure. For systems designed to protect smaller spaces being tested in the manufacturer's specified maximum volume enclosure, the pan size may be scaled down, but the pan area must be a minimum of 1.45 percent of the enclosure's footprint area. A 1 ft^2 (0.09 m^2) opening shall be provided on a wall directly across from the steel pan for the purpose of venting prior to system discharge. The top of the opening shall be within 2 in. (50 mm) of the top of the enclosure.

The steel pan shall be filled with a minimum of 2 in. (50 mm) of heptane meeting the requirements specified in Table 4.1.2.2. The heptane level shall be a minimum of 2 in. (50 mm) below the top of the pan. The heptane shall be ignited and allowed to burn freely with the vent open. Observations shall be made for the time of automatic operation of the extinguisher unit and time of extinguishment of the heptane fire.

The automatic operating extinguishment test shall be repeated, with the 2.5 ft^2 (0.23 m^2) square steel pan placed within 2 in. (50 mm) of the corner of the enclosure that is most remote from the location of the automatic extinguisher unit. The 1 ft^2 (0.09 m^2) opening shall be located in the corner wall of the enclosure, next to the steel pan. The heptane shall be ignited and allowed to burn freely with the vent open. Observations shall be made for the time of automatic operation of the extinguisher unit and time of extinguishment of the heptane fire.

All fires shall be extinguished within one minute after test fuel ignition.

4.3 Discharge Tests

4.3.1 Requirement

Pre-engineered and engineered clean agent extinguishing systems shall be capable of discharging 95 percent of the extinguishing agent within the maximum discharge time.

4.3.2 Test/Verification

Pre-engineered systems shall be assembled to include a piping configuration and discharge nozzles representative of the maximum specified limitations, as well as the maximum specified fill density. The agent storage container shall be conditioned to 70°F ± 5°F (21°C ± 3°C), and maintained at this temperature until the system is discharged. The system shall be discharged, and the discharge time recorded. This test must be performed successfully with the maximum amount of agent specified for each valve size.

Engineered systems shall be designed and assembled with a piping configuration producing no more than 90 percent of the 70ºF (21ºC) minimum nozzle design pressure, as well as the maximum specified fill density. The agent storage container shall be conditioned to 70°F ± 5°F (21°C ± 3°C), and maintained at this temperature for the duration of each test. The system shall be discharged, and the discharge time recorded. This test must be performed successfully with the maximum amount of agent specified for each valve size.

4.4 High Pressure Discharge Integrity Test

4.4.1 Requirement

All components in the system flow path shall be subjected to a maximum flow rate discharge test to determine their ability to withstand the reaction forces without damage that would impede the performance of the system. Following the test, discharge valves, selector valves, and check valves, if applicable, shall meet the requirements of Section 4.10 (Valve Leakage Test).

4.4.2 Tests/Verification

The agent storage container and valve assembly shall be filled with the applicable clean agent. For vaporizing liquid agents, the minimum specified fill density shall be used in testing. The assembly shall either be pressurized with nitrogen to the maximum working pressure, or pressurized with nitrogen to the working pressure and conditioned to the maximum specified storage temperature for a minimum of 24 hours.

Alternatively, water may be used as a substitute test medium. Calculations may be submitted by the manufacturer, deriving the appropriate quantity of water necessary to simulate the clean extinguishing agent with a maximum fill density. The water density used in the calculations shall be 62.4 lb/ft^3 (1000 kg/m^3).

The assembly shall be configured using the appropriate mounting brackets, and connected to a minimum piping configuration and discharge nozzle resulting in the largest system flow rate. The configuration shall incorporate all components in the system flow path, including discharge valves, selector valves, check valves, and all other mechanical and electrical elements normally connected to the discharge piping. Selector valves and check valves shall be tested in both the direction of normal flow and in the reverse direction. Selector and check valves shall be monitored for downstream leakage during this test. Any leakage through a check or selector valve that does not result in a pressure increase sufficient to actuate the system shall be deemed acceptable. All components shall be mounted and supported as specified by the manufacturer's published instructions.

Following the discharge test, the system shall be visually inspected for damage. Discharge valves, selector valves, and check valves included in the test shall be subjected to the requirements of Section 4.10 (Valve Leakage Test) at the system's working pressure.

4.5 Verification of Flow Calculation Limits

4.5.1 Requirement

The manufacturer's flow calculation method shall accurately predict the discharge time, nozzle pressure, and distribution of the clean extinguishing agent within established limiting parameters. The manufacturer shall provide and justify those limits to assist in the evaluation of the flow calculations.

4.5.2 Test/Verification

The manufacturer shall submit a table of limiting parameters for the flow calculation software, including, at minimum:

- The name of each parameter
- The minimum or maximum value for each parameter, as appropriate
- The engineering significance of each parameter to the calculation
- The engineering justification for the limiting value(s) of each parameter

The limit of testing conducted to date shall be an acceptable justification for a limiting value of a parameter. However, all limitations should generally be based on fluid mechanics and the properties of the agent.

The following list of parameters commonly addressed in such calculations shall be included in the manufacturer's table of limits, and technical justification shall be submitted for any exclusions. Acceptable technical justifications include that the parameter has been addressed by another parameter, or that it is not appropriate to the specific agent or calculation methodology.

- Minimum and maximum discharge time
- Minimum nozzle pressure
- Minimum and maximum agent storage container fill density
- Minimum and maximum pipe flow velocities
- Minimum and maximum nozzle orifice area ratio to pipe inlet area
- Proportion of piping volume to each nozzle
- Maximum variance in nozzle pressures in each piping configuration
- Type of pipe and pipe schedules
- Type of fittings
- Type of tee splits
- Minimum and maximum flow split for each type of tee split
- Maximum length of straight pipe runs
- Elevation changes
- Maximum imbalance in agent arrival time among nozzles
- Maximum imbalance in agent discharge time among nozzles
- Enclosure and pipe system temperature range
- Available working pressures
- Selector valve piping limitations for systems designed to protect multiple zones

Acceptability of technical justifications for limiting parameters and their values shall be based on the engineering judgment of FM Approvals.

4.6 Verification of Flow Calculation Method Test

4.6.1 Requirement

The manufacturer's flow calculation method shall predict the discharge time, nozzle pressure(s), and distribution of the clean extinguishing agent as follows:

- The predicted discharge time shall be within ±1.0 second of the measured discharge time for vaporizing liquid agents, or within ± 10 seconds for inert gas agents
- Each predicted nozzle pressure shall be within ±10 percent of the measured value
- The predicted weight of clean agent discharged from each nozzle shall be within ±10 percent of the measured value, or the value calculated from concentration measurements, as applicable
- The standard deviation of the percentage differences between each predicted agent weight from a nozzle and the measured agent weight shall not exceed 5 percent

4.6.2 Test/Verification

Prior to testing witnessed by FM Approvals, the manufacturer shall design various multiple nozzle systems, to be installed in enclosures of various volumes, that each incorporate limiting values for a minimum of two parameters. Each system must include at least three nozzles, and must contain at least one unbalanced split. All predicted values for tested parameters must meet or exceed the respective limiting values. A sufficient number of configurations shall be designed to address all flow calculation limiting parameters. Dimensioned as-built piping schematics, test results, and flow calculations for all such tests shall be submitted to FM Approvals for review; a minimum of five such results summaries, addressing all limits in aggregate, shall be submitted. If the results of these pre-tests are

acceptable, FM Approvals shall designate a minimum of two of the pre-tests to be re-run for witnessing to validate acceptance of the manufacturer's pre-testing. A minimum of an additional three tests shall be designed in collaboration with FM Approvals for further witnessing. This will provide a second set of data further validating the limits of the software.

The piping configuration, lengths, and sizes shall be verified against the schematic to ensure that the calculations shall accurately model the as-tested configuration.

The agent storage container shall be filled with the appropriate quantity of clean agent, and pressurized to the working pressure. The system and enclosure shall be maintained at a temperature equal to 70°F ± 5°F (21°C ± 3°C). Alternatively, if the environment is maintained at a temperature other than 70°F ± 5°F (21°C ± 3°C), appropriate temperature correction calculations shall be included. Testing with the system and enclosure at 70°F ± 5°F (21°C ± 3°C) will be considered sufficient for an Approved system and enclosure temperature range of 60°F to 80°F (15.6 °C to 26.7°C). If the manufacturer's calculation method is capable of predicting systems outside of this temperature range, verification tests shall be conducted throughout the specified temperature range.

The extinguishing system shall be discharged, and pressure measurements are to be recorded at the agent storage container and discharge nozzles throughout the discharge period. The pressure readings shall be recorded using a calibrated automated data acquisition system at a minimum sampling rate of 10 Hz.

One minute after the completion of discharge, the concentration of clean agent in each enclosure shall be measured using a calibrated concentration measuring device, and the quantity of discharged clean agent shall be calculated.

Alternatively, the agent discharged from each nozzle may be collected in such a manner as to not affect the discharge, and weighed or otherwise measured to determine quantities. Data and/or analysis to validate the collection methodology shall be provided by the manufacturer for review prior to testing. Acceptance of alternate collection methods is at the discretion of FM Approvals.

The test results shall be compared to the calculated projections to determine if the accuracy requirements of Section 4.6.1 have been met.

4.7 Cycle Operation Test

4.7.1 Requirement

All components required for system operation having moving parts shall operate through a total of 500 cycles at the working pressure without damage. Following the test, discharge valves, actuation devices, selector valves, and check valves shall continue to operate, and, if applicable, shall meet the requirements of Section 4.10 (Valve Leakage Test). Valves shall be successfully actuated via all applicable operating devices, and shall not display any increase in required force for mechanical operating devices or in actuation pressure for pneumatic operating devices.

4.7.2 Tests/Verification

The test samples shall include all components required for operation, including valves and other parts undergoing mechanical movement during system operation; electrical, pneumatic, and mechanical operating devices; switches; relays; indicators; and gauges. Valves shall be subjected to the working pressure and cycled from the fully closed to fully open position 500 times. At minimum, the largest and smallest valve sizes of each design shall be tested. Pressure actuated valves having the lowest ratio of available actuator torque to required operation torque shall also be tested. If applicable, manual actuators shall include the maximum length of cable, number of pulleys, etc.

Subsequent to the cycle operation test, each component shall be visually inspected for damage. Discharge valves, selector valves, and check valves included in the test shall continue to operate, and be subjected to Section 4.10 (Valve Leakage Test) at the system's working pressure. Discharge valves shall be actuated by all available discharge devices. The pressure required for pneumatic operating devices shall be recorded, and manual controls shall be subjected to Section 4.16.3 (Manually Operated Controls).

Any system components that are replaced after each operation, such as pyrotechnic actuators, shall be evaluated by operation of a minimum of 30 samples. All shall operate within the manufacturer's specified parameters.

4.8 Equivalent Length Determination

4.8.1 Requirement

The equivalent length for all components in the flow path of an engineered clean agent system, other than discharge nozzles, shall be determined for incorporation into system design calculations. The equivalent lengths for all applicable components shall be included in the manufacturer's design, installation, operation, and maintenance manual.

4.8.2 Tests/Verification

Each sample shall be installed between two test pipes equipped with piezometer rings. The test pipes shall be of the same nominal diameters as the sample. Using water as a test medium, the friction loss between the piezometer rings shall be measured at a minimum of four flow rates. The test sample shall be removed from the test configuration, and the friction losses at the same flow rates determined. The friction loss of the sample is determined by subtracting the loss of the pipe from the loss for the pipe and test sample combination. The minimum flow velocity used in testing shall be that required for completely turbulent flow, based upon the nominal pipe size of the component under test and schedule 40 pipe actual inside diameters.

A Reynolds Number above 4000 is indicative of turbulent flow. For a circular cross-section pipe, the Reynolds Number (Re) can be calculated as follows:

For U.S. Customary units:

$$\mathrm{Re} = 7741.9\frac{ud}{v}$$

Where:

Re = Reynolds Number, non-dimensional
u = velocity, ft/s
d = diameter of the fully-filled pipe, in
v = kinematic viscosity, cSt, where 1 cSt = 10^{-6} m^2/s, = approximately 1, for water at 68.4° (20°C)

For SI units:

$$\mathrm{Re} = \frac{ud}{v}$$

Where:

Re = Reynolds Number, non-dimensional
u = velocity, m/s
d = diameter of the fully-filled pipe, m
v = kinematic viscosity, m^2/s

The friction loss of the sample shall be converted to an equivalent length in feet (meters) of pipe, using a Hazen-Williams coefficient of 130. If component designs are proportional over a range of sizes, the manufacturer may submit equivalent length data for the range. In this case, at the discretion of FM Approvals, the smallest and largest sizes from this range may be tested to verify the manufacturer's data. Alternatively, equivalent length may be determined by actual discharge of agent from the agent storage container.

Hazen-Williams Equation:

$$p = \frac{cQ^{1.85}}{C^{1.85}d^{4.87}}$$

Where:

p	loss per unit length, psi/ft (kPa/m)
c	constant = 4.52 for U.S. customary units (= 10.67 in SI units.)
Q	flow rate, gal/min (m^3/min)
C	Hazen-Williams pipe coefficient = 130
d	internal pipe diameter, in (m)

4.9 Agent Storage Containers

4.9.1 Construction Design

4.9.1.1 Requirements

Agent storage containers shall be fabricated, tested, approved, equipped, and provided with labeling in accordance with recognized international standards, such as the current specifications of the ASME *Boiler and Pressure Vessel Code*, Section VII, or the requirements of U.S. Department of Transportation, Title 49, Code of Federal Regulations, Parts 171 to 180, or equivalent national codes for the country of use. The design working pressure shall be in accordance with the pressure at the manufacturer's maximum specified installation temperature.

4.9.1.2 Tests/Verification

All documentation concerning the fabrication and testing of the cylinders shall be provided to FM Approvals for initial evaluation of the following:

- Verification that the pressure vessel standard is appropriate for the system storage pressure, and appropriate to the jurisdiction in which the equipment will be used. If the standard does not meet this requirement, there may be additional minimum criteria established by FM Approvals.
- Verification that the design is in accordance with the standard. Typical verification includes a review of certification to manufacture to the standard, minimum wall thickness calculations, authorized materials, material tests, and general chemical analysis tests.

Further verification that the manufacturer is capable of producing storage containers in accordance with the relevant standard shall be required at the discretion of FM Approvals. Typically, verification includes volumetric expansion and hydrostatic pressure tests in accordance with the applicable standard(s).

4.9.2 Long Term Leakage Test

4.9.2.1 Requirement

Agent storage container assemblies for vaporizing liquid agents shall not leak in excess of 0.5 percent of the minimum system charge weight when monitored over a one year period at 70°F ± 5°F (21°C ± 3°C). The allowable leakage value is based upon a 2 to 1 safety factor applied to a maximum 5 percent total leakage over a five year inspection period.

Agent storage container assemblies for inert gas agents shall not leak in excess of the mass equivalent to 0.5 percent of the nominal storage pressure, based upon the minimum size container intended for use with a specific discharge valve. The allowable leakage value is based upon a 2 to 1 safety factor applied to a maximum 5 percent total leakage over a five year inspection period

4.9.2.2 Tests/Verification

For vaporizing liquid agents, a minimum of three sample agent storage container assemblies of each leak path design and size shall be filled with the applicable clean agent at the maximum specified fill density, and pressurized to the system's specified working pressure. For inert gas agents, containers shall be pressurized to the system's specified working pressure. Test sample assemblies shall incorporate all components subjected to the working pressure, including operating devices. For vaporizing liquid agents, the test shall be repeated for all a storage container installation orientations specified by the manufacturer.

Each sample shall be weighed at 0, 1, 3, 6, and 12 months, and where applicable, the projected weight loss over a one year period shall be extrapolated. The test shall be suspended if the calculated leakage at any time exceeds the allowable quantity. Subsequent to the one year test period, one sample of each valve design and size shall be successfully discharged using one of the manufacturer's compatible operating devices. The duration of this test may be reduced at the sole discretion of FM Approvals.

4.9.3 30-Day Maximum Temperature Leakage Test

4.9.3.1 Requirements

Agent storage container assemblies shall not leak in excess of 0.042 percent when conditioned to the specified maximum system operating temperature for a 30 day period. The allowable leakage value is 1/12 of the one year allowable leakage, as specified in Section 4.9.2.1.

4.9.3.2 Tests/Verification

A minimum of three agent storage container assemblies of each design and size shall be prepared as described in Section 4.9.2.2.

The samples shall be weighed prior to the elevated temperature exposure, and shall be subjected to the maximum specified operating temperature for 30 days. Following the exposure period, the samples shall be weighed to determine the amount of extinguishing agent lost. One sample of each valve design and size shall be successfully discharged using one of the manufacturer's compatible operating devices.

4.9.4 30-Day Minimum Temperature Leakage Test

4.9.4.1 Requirements

Agent storage container assemblies shall not leak in excess of 0.042 percent when conditioned to the specified minimum system operating temperature for a 30 day period. The allowable leakage value is 1/12 of the one year allowable leakage, as specified in Section 4.9.2.1.

4.9.4.2 Tests/Verification

A minimum of three sample agent storage container assemblies of each design and size shall be prepared as described in Section 4.9.2.2.

The samples shall be weighed prior to the low temperature exposure, and shall be subjected to the minimum specified operating temperature for 30 days. Following the exposure period, the samples shall be weighed to determine the amount of extinguishing agent lost. One sample of each valve design and size shall be successfully discharged using one of the manufacturer's compatible operating devices.

4.9.5 Hydrostatic Integrity

4.9.5.1 Requirement

Agent storage containers shall be hydrostatically tested without failure at a pressure equal to 1.5 times the rated pressure of the pressure relief device, or in accordance with the applicable published standard, whichever pressure is greater. Allowable standards shall be those acceptable to the authority having jurisdiction, based on the intended market for the system. Approval shall be limited to installations within jurisdictions accepting the standard to which the containers have been manufactured. No cracking, fracture, or failure to retain the test pressure shall be allowed.

4.9.5.2 Tests/Verification

Each sample shall be subjected to the required test pressure, using water as the pressurizing medium. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer.

Two samples of each container size intended for use with the system shall be tested. Container designs consisting of the same diameter, wall thickness, and material of construction, but with differing heights, may be evaluated by testing selected representative samples rather than samples of all container heights.

Samples that deviate from the calculated minimum wall thickness (refer to Section 4.1.1.2) may be accommodated by increasing the test pressure in proportion to the wall thickness. This may be used for up to a maximum difference of 20 percent.

At the sole discretion of FM Approvals, physical testing may be waived for pressure vessels being manufactured under continuous third-party surveillance to a recognized and appropriate pressure vessel regulation. In these circumstances, in lieu of physical testing, the manufacturer shall provide adequate documentation detailing continuous (every lot) third-party oversight of the pressure vessel manufacturing, sample test results, and appropriate certification documentation for the overseeing body.

4.9.6 Permanent Volumetric Expansion

4.9.6.1 Requirement

Permanent volumetric expansion testing is required under some pressure vessel standards. If required by the standard to which the storage container is designed, such tests shall be conducted in accordance with that standard.

When subjected to the proof test pressure, the permanent volumetric expansion of a storage container shall not exceed 10 percent of the total expansion. The proof test pressure shall be as specified in the ASME *Boiler and Pressure Vessel Code*, Section VII, or the U.S. Department of Transportation, Title 49, Code of Federal Regulations, Parts 171 to 180, or the equivalent national codes for the country of use. In cases where the pressure vessel is not tested or marked in accordance with one of these specifications, the proof test pressure shall be equal to three times the extinguishing system's working pressure.

4.9.6.2 Tests/Verification

Each sample shall be subjected to the required test pressure, using water as the pressurizing medium. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer. The total expansion of the cylinder shall be measured. The applied pressure shall then be removed from the sample, and the permanent volumetric expansion shall be measured.

Two samples of each container size intended for use with the system shall be tested. Cylinder designs consisting of the same diameter, wall thickness, and material of construction, but with differing heights, may be evaluated by testing selected representative samples rather than samples of all cylinder heights.

At the sole discretion of FM Approvals, physical testing may be waived for pressure vessels being manufactured under continuous third-party surveillance to a recognized and appropriate pressure vessel regulation. In these circumstances, in lieu of physical testing, the manufacturer shall provide adequate documentation detailing continuous (every lot) third-party oversight of the pressure vessel manufacturing, sample test results, and appropriate certification documentation for the overseeing body.

4.10 Valve Leakage Test

4.10.1 Requirement

Discharge valves shall not display visible leakage when subjected to a pressure equal to the nominal rating of the system's pressure relief device for one minute. Selector and check valves shall not leak more than 1 fluid ounce (29.6 ml) per inch of nominal valve size per hour when subjected to a pressure equal to one-half the nominal rating of the system's pressure relief device or one-half of the cylinder test pressure, whichever is higher, for one minute.

4.10.2 Tests/Verification

The outlet of the valve shall remain open, while the valve inlet is pressurized at a rate not exceeding 300 psi (20.7 bar) per minute. The pressure shall be increased until the required pressure is achieved, and the pressure shall be maintained for one minute. Water shall be used as the pressurizing medium, and leakage from the valve outlet shall be collected for measurement following the one minute test period.

If a valve design is such that leakage is likely to occur at a lower pressure than half the pressure relief device's setting, the valve shall also be tested at the lower pressure.

4.11 Hydrostatic Pressure Test

4.11.1 Requirement

All components subjected to system pressure, either during storage or system discharge, shall withstand the pressure described in Section 4.9.5 (Hydrostatic Integrity) for one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.11.2 Tests/Verification

Each sample shall be subjected to the required test pressure. For the final 20 percent of the required pressure, the rate of pressure increase shall be no more than 10 percent per minute. The required test pressure shall be maintained for a minimum of one minute, or in accordance with the applicable published standard, whichever is longer.

Leakage is acceptable during the hydrostatic tests, as long as the pressure source is adequate to maintain the required test pressure.

4.12 Pressure Relief Devices

4.12.1 Pressure Relief Operation

4.12.1.1 Requirement

The pressure relief device pressure ratings of agent storage container and valve assemblies shall be selected as specified in Section 3.2.8. The operating pressure of the device shall be within -10/+0 percent of the manufacturer's specified rating. The operating pressure of pressure relief devices used elsewhere in the system shall fall within the manufacturer's specified rating.

4.12.1.2 Test/Verification

A minimum of ten pressure relief device assemblies of each type shall be pressurized until operation. If the device does not contain a rupturing component, but rather operates similarly to a pressure relief valve, the same device shall be subjected to all ten trials. Pressure may be increased rapidly to 85 percent of the device's rated pressure, and then shall be increased until operation at a rate no greater than 10 percent per minute. The operating pressure shall be recorded.

4.12.2 Pressure Relief Calculations

4.12.2.1 Requirement

Documentation shall be submitted to verify that the construction and size of the pressure relief device complies with the flow capacity requirements.

The construction and size of the burst disc and dispersion device shall, at a minimum, be appropriate for the system pressure at the maximum specified operating temperature.

4.12.2.2 Tests/Verification

Appropriate documentation and calculations shall be submitted to verify that the construction and size of the pressure relief device complies with the flow capacity requirements specified in CGA Pamphlet S-1.1, Safety Relief Devices Standards – Cylinders for Compressed Gases, or equivalent.

4.13 Mounting Device Test

4.13.1 Requirement

An extinguishing system mounting bracket shall not show evidence of permanent distortion or other damage when subjected to a static load equal to five times the fully charged weight of the extinguishing system.

4.13.2 Test/Verification

An extinguishing system mounting bracket shall be assembled in its intended orientation. A static load equal to five times the fully charged weight of the system, but not less than 100 pounds (45.3 kg), shall be applied vertically downward to the bracket. The load shall be maintained for 5 minutes. The mounting bracket shall be observed for damage throughout the 5 minute period.

The mounting device test shall not apply to mounting brackets for containers that are intended to be directly supported by the floor.

4.14 Flexible Hose

4.14.1 Low Temperature Resistance

4.14.1.1 Requirement

Flexible hoses shall withstand damage when conditioned at the minimum specified extinguishing system storage temperature. Following the conditioning period, the flexible hose shall withstand the minimum specified bending radius, as well as the hydrostatic pressure described in Section 4.11 (Hydrostatic Pressure Test) for a period of one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.14.1.2 Tests/Verification

One sample of each representative size flexible hose shall be tested. Each hose assembly shall be conditioned for 16 hours at the minimum specified storage temperature. The sample shall be maintained at the minimum temperature and bent to the minimum specified bending radius. Bending shall be performed smoothly and continuously within an approximate 10 second time interval.

The flexible hose shall be visually inspected for cracking or other damage. Subsequent to this inspection, hose shall be subjected to the required test pressure for a period of one minute, or in accordance with the applicable standard, whichever is longer. No rupture or separation from end connections shall occur.

4.14.2 Resilience

4.14.2.1 Requirement

Flexible hoses shall withstand damage and remain functional after 3000 cycles of flexure to the maximum specified angle from straight. Following the cycle test, flexible hose shall withstand the hydrostatic pressure described in Section 4.11 (Hydrostatic Pressure Test) for one minute. No cracking, fracture, or failure to retain the test pressure shall be permitted.

4.14.2.2 Test/Verification

Each hose assembly shall be conditioned for 16 hours at 70°F ± 5°F (21°C ± 3°C). The sample shall be maintained at this temperature and bent to the minimum specified bending radius or to the maximum specified angle. Bending shall be performed smoothly and continuously. The sample shall then be straightened to complete one cycle. The bending and straightening cycle shall be repeated for a total of 3000 cycles.

The flexible hose shall be visually inspected for cracking or other damage. Subsequent to this inspection, hose shall be subjected to the required test pressure for a period of one minute, or in accordance with the applicable standard, whichever is longer. No rupture or separation from end connections shall occur.

4.15 Liquid Level Indicators

4.15.1 Requirements

For vaporizing liquid agents only, a liquid level indicator shall accurately indicate the quantity of clean agent contained in an agent storage container within a tolerance of ± 2.5 percent. Other methods for monitoring the agent quantity in an agent storage container (e.g. continuous weight monitoring devices) shall be evaluated at the discretion of FM Approvals.

4.15.2 Tests/Verification

Sample agent storage containers shall be individually filled with the minimum and maximum specified fill densities. The containers shall be weighed, and the agent weight shall be recorded. Cylinder designs consisting of the same diameter, wall thickness, and material of construction, but with differing heights, may be evaluated by testing selected representative samples rather than samples of all cylinder heights.

The samples shall be conditioned at the minimum specified operating temperature, at 70°F ± 10°F (21°C ± 5.5°C), and at the maximum specified operating temperature for a period of 24 hours. Subsequent to each conditioning period, the liquid level in the container shall be measured, and the agent weight calculated based on the manufacturer's liquid level indicator charts, tables, or equations. The calculated weight shall be compared to the actual agent weight in the container. The calculated weight shall be within ± 2.5 percent of the measured value.

4.16 Control and Actuator Operation

4.16.1 General

4.16.1.1 Requirement

All control devices shall operate under the most adverse system pressure when conditioned to the maximum and minimum specified installation temperatures.

4.16.1.2 Tests/Verification

A minimum of one sample of each device shall be conditioned to the minimum specified installation temperature for 16 hours. While still at that temperature, the device shall be installed on the valve for which it is designed and operated and display no hesitation, partial operation, or other failure. Devices operated by pressure shall be tested at maximum or minimum working pressure, whichever is more conservative for the design of the specific component. If the most adverse condition is not easily discernable, the device shall be operated at both extremes of pressure.

A minimum of one sample of each device shall be conditioned at the maximum specified installation temperature for 16 hours, and the evaluations described above shall be repeated.

4.16.2 Electrically Operated Devices

4.16.2.1 Requirement

Electrically operated control devices shall operate properly at 85 and 110 percent of the rated voltage while at maximum and minimum specified installation temperatures.

4.16.2.1 Tests/Verification

A minimum of one sample of each device shall be conditioned in accordance with the parameters described in Section 4.16.1.2. Following the conditioning period, each sample shall operate when supplied with 85 percent of rated voltage, and again when supplied with 110 percent of rated voltage. The device shall display no hesitation, partial operation, or other failure.

4.16.3 Manually Operated Controls

4.16.3.1 Requirement

Manual controls shall operate properly with applied forces no greater than 40 lb (178 N), linear movement no more than 14 in. (355 mm), nor rotational movement of over 270 degrees when configured with the most adverse arrangement specified by the manufacturer's installation instructions.

4.16.3.2 Tests/Verification

A minimum of one sample of each device shall be tested. Calibrated force gauges, torque meters, and measuring tapes shall be used to measure operational requirements. Tests shall be conducted under the most adverse conditions with respect to system working pressure, if applicable. Devices using flexible mechanical cable actuation shall be tested with the most adverse cable routing, including the maximum cable length and number of changes of direction. No impairment of operation shall be allowed.

4.16.4 Pilot Operated Controls

4.16.4.1 Requirement

Pneumatically operated pilot-secondary and master-secondary cylinder arrangements of the most adverse specified configuration shall operate all connected agent storage containers within one second of each other.

4.16.4.2 Tests/Verification

The pilot cylinder or master cylinder shall be pressurized to its working pressure and conditioned to the minimum specified storage temperature for 16 hours. Secondary cylinders shall be pressurized to their working pressures and conditioned to the maximum specified storage temperature for 16 hours. The maximum number of secondary cylinders shall be connected to the pilot or master cylinder through the most restrictive piping arrangement permitted by the manufacturer's installation instructions. The pilot or master cylinder shall be actuated, and the time interval between operation of the pilot or master cylinder and the last secondary cylinder shall be measured. An automated data acquisition system, capable of recording pressure readings for the pilot and most remote secondary cylinder at a minimum of 10 Hz, shall be used to record the timing. The most remote secondary cylinder shall operate within one second of the first significant pressure decrease in the master cylinder or first secondary cylinder, as applicable.

For inert gas systems using back pressure actuation, if the maximum number of secondary cylinders exceeds 20, the data obtained from tests of 10 and 20 cylinders can be extrapolated to the maximum number of cylinders to determine whether operation can be expected within the maximum allowable 1 second interval.

4.16.5 Mechanical Time Delay Assemblies

4.16.5.1 Requirement

Mechanical time delay assemblies shall delay the actuation of a system within -0/+20 percent of the manufacturer's specified delay time, throughout the stated operational temperature range and range of time delay settings.

4.16.5.2 Tests/Verification

The assembly shall be adjusted to the minimum delay time setting and conditioned at the minimum specified installation temperature for 16 hours. While still at the minimum installation temperature, the assembly shall be pressurized to the minimum working pressure, and the time delay until release of the pressure shall be recorded. The test shall be repeated with the assembly adjusted to the maximum time delay setting, and then again with the assembly adjusted to an intermediate setting.

The assembly shall be adjusted to the minimum delay time setting and conditioned at the maximum specified installation temperature for 16 hours. While still at the maximum installation temperature, the assembly shall be pressurized to the maximum working pressure, and the time delay until release of the pressure shall be recorded. The test shall be repeated with the assembly adjusted to the maximum time delay setting, and then again with the assembly adjusted to an intermediate setting.

4.16.6 Pressure Operated Audible Alarm Devices

4.16.6.1 Requirement

Audible alarm devices shall operate effectively and continuously without failure, throughout the range of system operating pressures, with a minimum sound level of 90 decibels measured 10 feet (3.05 m) from the device.

4.16.6.2 Tests/Verification

The device shall be mounted not less than 10 ft (3.05 m) above the ground in its normal orientation. A sound level meter shall be positioned in a vertical plane through the device's centerline, 10 ft (3.05 m) away from the mounting plane, and 5 ft (1.5 m) above the ground. The meter shall be oriented to obtain the strongest response.

The sound meter shall comply with ANSI/ASI S1.4-1983, *Specification for Sound Level Meters*, and Amendment S1.4A-1985. Measurements are to be made using "C" weighting network and the fast response setting.

The test shall be conducted in a free field environment having an ambient noise level a minimum of 10 decibels below the measured level produced by the alarm. The alarm shall be operated at its minimum specified pressure for five hours and at the maximum specified pressure for one hour.

4.17 Dielectric Withstand

4.17.1 Requirement

Electrical components shall withstand an applied voltage between all terminals provided for external connections and ground, as well as between all combinations of individual connections. There shall be no breakdown of the insulation between the test points. Components shall continue to function normally subsequent to this test.

4.17.2 Tests/Verification

For a device with a rated voltage not exceeding 90 V, the test voltage shall be equal to 500 V. For all other devices, the test voltage shall be calculated as 1000 V plus two time the rated voltage of the circuit. The required voltage shall be applied between each terminal and ground, and between all individual terminals. The voltage shall be increased steadily to the specified value in a period of not less than 10 seconds, and maintained for a minimum of 60 seconds.

4.18 Corrosion – Salt Spray

4.18.1 Requirement

System components shall withstand a 240 hour exposure to the test described in Section 4.18.2 without incurring damage that would impair function. Following the exposure period, the system shall be successfully discharged using one of the manufacturer's compatible operating devices.

4.18.2 Tests/Verification

Test samples shall be selected to represent all material combinations and configurations. A minimum of one agent storage container assembly, including the mounting bracket, shall be included among the test samples. Actuation devices with moving parts subject to fouling from external corrosion shall also be subject to this test. Test sample agent storage containers shall be pressurized to the working pressure, but need not contain the actual agent. Discharge nozzles manufactured from a corrosion resistant material are not subject to salt fog testing, provided that material specifications are submitted for review.

The samples shall be exposed to salt spray (fog) as specified by ASTM B117, *Standard for Salt Spray (Fog) Testing*. The salt solution shall consist of 20 percent (by weight) of common salt (sodium chloride) dissolved in deionized water with a pH between 6.5 and 7.2 and a specific gravity between 1.126 and 1.157.

Following the exposure to the salt fog, the sample shall remain fully functional and exhibit no corrosion, galvanic action, loss of legibility of markings, or separation of protective coatings which would impair future functionality. Superficial discoloration with no substantial attack of the underlying material shall be acceptable. The fully charged agent storage container and valve assembly shall be successfully discharged using one of the manufacturer's compatible operating devices.

4.19 Corrosion – Stress Cracking

4.19.1 Requirement

Extinguishing system components shall be resistant to stress corrosion cracking resulting from exposure to the processes described in Section 4.19.2. Following the exposure period, the samples shall not show evidence of cracking, delamination, or degradation.

4.19.2 Test/Verification

4.19.2.1 Copper Based Parts (Ammonia Test)

Devices manufactured of copper alloys with a zinc content exceeding 15 percent shall be exposed to a moist ammonia environment. The inlet end of each sample shall be filled with deionized water and sealed with a non-reactive material (e.g., plastic cap) so as to prevent the introduction of the ammonia atmosphere to the interior of the component. The samples to be tested shall be free from any non-permanent protective coating and, if necessary, shall be degreased. If a permanent coating is an inherent part of the design, such coating shall be subjected to tests as deemed necessary by FM Approvals to evaluate its protective integrity. The samples shall be tested in their intended orientation. Samples shall be assembled using the manufacturer's specified torque on threaded connections and flange bolts to replicate the as-installed loads.

There shall be provisions in the test chamber to prevent droplets of condensation from falling from the top of the enclosure directly onto the samples. Such a shield or other means shall be constructed of glass or other non-reactive materials.

The samples shall be exposed to the moist ammonia-air mixture maintained in a glass chamber with a volume of 0.73 ± 0.34 ft^3 (0.02 ± 0.01 m^3).

Aqueous ammonia having a density of 5.86×10^{-5} lb/ft^3 (0.94 g/cm^3) shall be maintained in the bottom of the chamber, approximately 1.5 in. (40 mm) below the bottom of the samples. The volume of ammonia to be used shall be determined by multiplying the enclosure volume in ft^3 (L) by 0.075 gal/ft^3 (10 L/m^3). This will result in approximately the following atmospheric concentrations: 35 percent ammonia, 5 percent water vapor, and 60 percent air. Prior to beginning the exposure, the chamber shall be conditioned to a temperature of 93°F ± 4°F (34°C ± 2°C) for a period of not less than one hour, and shall be maintained at this temperature throughout the exposure period. The moist ammonia-air mixture shall be maintained at essentially atmospheric pressure. Provision shall be made for venting the chamber, such as by the use of a capillary tube, to avoid buildup of pressure.

Following exposure to the moist ammonia environment for a period of 10 days, the samples shall be removed, rinsed in potable water, and air dried. Following a minimum two-day drying period, visual examination of the samples shall be made.

4.19.2.2 Austenitic, Ferritic, and Duplex Stainless Steel Parts (Boiling Magnesium Chloride Test)

Samples shall be degreased and exposed to a boiling magnesium chloride solution for a period of 500 hours, in accordance with ASTM G36, Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution.

Samples are to be placed in a flask fitted with a wet condenser. The flask shall be approximately half filled with a nominal 42 percent by weight magnesium chloride solution, placed on a thermostatically-controlled electrically-heated mantle, and maintained at a boiling temperature of 302 °F ± 4 °F (150 °C ± 2 °C).

Following exposure, the samples shall be removed and rinsed in potable water. Following a two-to four-day drying period, visual examination of the samples shall be made.

4.19.2.3 Parts Manufactured from Other Materials

Parts manufactured from other materials shall withstand comparable tests, based on the type of material employed, at the sole discretion of FM Approvals.

4.20 High Temperature Exposure

4.20.1 Requirement

Components, such as nozzles, that are exposed to the protected space shall not show significant deformation, blistering, or fracture following exposure to an elevated temperature as detailed in Section 4.20.2. In the case of a nozzle, no cracking or distortion that would potentially alter discharge characteristics shall be allowed.

4.20.2 Test/Verification

The component shall be placed in an oven and heated to 1470 ± 20 ºF (800 ± 11ºC) for a period of 15 minutes. Following this exposure, the nozzle shall be removed and promptly submerged in a water bath with a temperature of 60 ± 10 ºF (15 ± 6ºC).

4.21 Aging Tests – Plastic Materials

4.21.1 Air-Oven Aging Test

4.21.1.1 Requirements

Nonmetallic components, including valves, valve parts, siphon tubes and other parts subjected to the flow of clean agent, and mounting brackets, shall be subjected to air-oven aging tests at 212°F (100°C). There shall be no cracking or crazing as a result of this test. Subsequent to exposure, valves and valve parts shall then be subjected to the requirements of Section 4.11 (Hydrostatic Pressure Test), agent storage containers shall be subjected to the requirements of Section 4.9.5 (Hydrostatic Integrity), and mounting brackets shall be subjected to the requirements of Section 4.7 (Mounting Device Test).

4.21.1.2 Test/Verification

Samples shall be subjected to air-oven aging tests for 180 days at 212°F (100°C), and then allowed to cool a minimum of 24 hours in air at 74°F (23°C) at 50 percent relative humidity. At the conclusion of the test, the samples shall be inspected for cracking or crazing. The samples shall then be subjected to the applicable tests listed in Section 4.21.1.1.

4.21.2 Ultraviolet Light and Water Test

4.21.2.1 Requirements

Nonmetallic components, including valves, exposed valve parts, and mounting brackets, shall be exposed to ultraviolet light and water for 720 hours in accordance with Table X3.1, Condition 1, of ASTM G 155-00, *Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials*. At the conclusion of the test, there shall be no cracking or crazing of the component. Valves and valve parts shall then be subjected to the requirements of Section 4.11 (Hydrostatic Pressure Test). Mounting brackets shall be subjected to the requirements of Section 4.13 (Mounting Device Test).

4.21.2.2 Test/Verification

Samples shall be exposed to ultraviolet light and water for 720 hours. The samples shall be inspected for cracking and crazing after 360 hours. If no cracking or crazing is apparent, the exposure shall continue for the full 720 hours. During each operating cycle, each sample shall be exposed to light and water spray for 18 minutes and to only light for 102 minutes (total 120 minutes). The air temperature within the apparatus during operations shall be 109 ± 4.5ºF (43 ± 2.5ºC) and the relative humidity 30 ± 5 percent. At the conclusion of the test, the samples shall be inspected for cracking or crazing. The samples shall then be subjected to the applicable tests listed in Section 4.21.2.1.

4.21.3 Exposure to Clean Agent Test

4.21.3.1 Requirements

Plastic siphon tubes or other plastic wetted components shall not show any signs of degradation following exposure to the clean extinguishing agent.

4.21.3.2 Test/Verification

Three 1/2 in. (12.7 mm) wide ring samples shall be cut from a plastic siphon tube and immersed in a container filled with the clean extinguishing agent. Non-cylindrical samples shall be cut to expose their cross-sections and be of approximately 1/2 in. (12.7 mm) in length, perpendicular to the cut, if longer than that dimension in their initial configuration. The container shall be sealed and conditioned to the maximum specified operating temperature for a period of 90 days. The samples shall be subsequently rinsed in water and allowed to dry for 24 hours in air at 70°F ± 5°F (21°C ± 3°C) and 50 percent relative humidity. At the conclusion of the test, the samples shall be inspected for signs of degradation.

4.22 Elastomeric Materials Tests

4.22.1 Requirements

Elastomers used in clean agent extinguishing systems shall have a tensile strength of not less than 500 psi (34.5 bar), an ultimate elongation of not less than 100 percent, and a tensile set of not more than 19 percent. Tensile strength, ultimate elongation, and tensile set shall be determined in accordance with ASTM D 412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers - Tension*, Method A, with exceptions as stated in Section 4.22.2.

4.22.2 Tests/Verification

For standard elastomers, the material manufacturer's certificates of compliance verifying the conformance to the performance requirements listed in Section 4.22.1 shall be considered acceptable. The test certificates shall demonstrate that the tests were conducted by an ISO 9000 certified facility, and that the test equipment was calibrated by an ISO 17025 (*General Requirements for the Competence of Testing and Calibration Laboratories*) certified agency. Where such certifications are not available, tests of the elastomer shall be conducted.

Tensile strength, ultimate elongation, and tensile set shall be determined in accordance with ASTM D 412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension*, Method A, with the exception that, for tensile set determinations, the elongation shall be maintained for 3 minutes, and the tensile set shall be measured 3 minutes after release of the specimen. The elongation of a specimen for a tensile set determination shall be such that the 1 in. (25 mm) spacing of the benchmarks increases to 3 in. (76 mm). If a specimen breaks outside the benchmarks, or if either the measured tensile strength or ultimate elongation of the specimen is less than the required value, an additional specimen shall be tested, and those results shall be considered final. Results of tests for specimens that break in the curved portion just outside the benchmarks shall be allowed if the measured strength and elongation values are within the minimum requirements.

4.23 Pressure Gauges and Supervisory Pressure Switches

4.23.1 Accuracy

4.23.1.1 Requirement

Agent supply container pressure gauges shall exhibit accuracy within the limits of Table 4.23.1.1.

Table 4.23.1.1 *Pressure Gauge Limits*

Area of Range	***Accuracy Required, percent***
Zero Point	-0/+12
Low Pressure Alarm Point	± 6
Working Pressure	± 4
Full Scale	± 15

Supervisory pressure switches shall activate within ±6 percent of the low pressure alarm point under falling pressure. Samples must be tested after being conditioned at the minimum specified operating temperature, at 70°F ± 10°F (21°C ± 5.5°C), and at the maximum specified operating temperature for a period of four hours.

Maintenance gauges for inert gas systems shall demonstrate accuracy grade 2A (0.5 percent of full scale throughout the marked range), as specified in ANSI/ASME B40.1

4.23.1.2 Test/Verification

Readings of a minimum of three sample agent storage container gauges and switches of each type at each of the points specified shall be compared to readings of a calibrated test gauge having a minimum accuracy of ±1 percent. A test gauge having a minimum accuracy of ± 0.25 percent shall be used to evaluate an inert gas system maintenance gauge at each of its major scale divisions. Readings shall be taken in both ascending and descending order. All sample gauge readings and pressure switch activation points shall match those of the test gauge within the tolerances specified in Section 4.23.1.1.

4.23.2 Impulse Resistance

4.23.2.1 Requirement

Pressure gauge and supervisory pressure switch accuracy shall remain within the limits of Table 4.23.1.1 after 1000 cycles of pressure impulse as follows:

- from 40 to 175 percent of the system's working pressure for vaporizing liquid systems
- over the operable pressure range for inert gas systems

4.23.2.2 Test/Verification

One sample gauge and switch of each type shall be connected to an apparatus capable of varying pressure from over the range described in Section 4.23.2.1 six times per minute. After 1000 cycles have been completed, the sample shall be retested for accuracy as described in Section 4.23.1.

4.24 Automatic Extinguisher Unit Tests

In addition to the applicable requirements listed elsewhere in this standard, operating devices associated with automatic extinguisher units, unless an FM Approved automatic fire sprinkler shall be subjected to the following performance requirements. Additional tests may be required depending on design features, results of any tests, or material application, at the discretion of FM Approvals.

4.24.1 Assembly Load/Frame Strength

4.24.1.1 Requirements

The frame of a heat responsive automatic operating device shall be capable of withstanding twice the assembly load without sustaining permanent elongation or deformation in excess of 0.2 percent of the distance between the load bearing parts of the device.

4.24.1.2 Test/Verification

A minimum of ten previously untested samples shall be individually tested to determine the assembly load. With the threaded portion of the device restrained from movement, the heat responsive element of the test sample shall be removed and the negative axial deflection of the frame, due to the release of the assembly, recorded. A force necessary to return the deflection of the frame to the original zero position shall be reapplied and the value of the force recorded.

Each of the devices shall then be subjected momentarily (1 to 5 seconds) to twice the sum of the recorded force plus the force applied to the device as a result of the system's specified working pressure. The amount of permanent set after the load application shall be determined.

4.24.2 Strength of Heat Responsive Element

4.24.2.1 Requirements

The lower tolerance limit for bulb strength shall be greater than two times the upper tolerance limit for assembly load of a heat responsive automatic operating device based on calculations with a degree of confidence of 0.99. Calculations shall be based on the Normal or Gaussian Distribution except where another distribution can be shown to be more applicable due to manufacturing or design factors. The method for calculating the upper and lower tolerance limits is shown in Appendix D.

4.24.2.2 Test/Verification

The results of Section 4.24.1 (Assembly Load/Frame Strength) shall form the basis for the upper tolerance limit for the assembly load calculations. The lower tolerance limit for bulb strength shall be determined using the results obtained from subjecting a minimum of 20 sample bulbs to an increasing load until the bulbs fail. Each test shall be conducted with the bulb mounted in hardened steel inserts with seating surfaces or dimensions which conform to the actual mating components of the automatic operating device. The inserts shall have a hardness within the range Rockwell C 38-50 (see Figure E-7). They shall be provided by the manufacturer each time the test is specified. The load shall be applied at a rate of compression not exceeding 0.05 in./min (1.27 mm/min). The results obtained from the two sets of data shall be used for the tolerance limit calculations as described in Appendix D, Tolerance Limit Calculations.

4.24.3 Hydrostatic Strength

4.24.3.1 Requirements

Heat responsive automatic operating devices shall be capable of withstanding, without rupture, an internal hydrostatic pressure equal to the maximum specified working pressure or 700 psi (48.3 bar), whichever is higher, for a period of 1 minute.

4.24.3.2 Test/Verification

Each sample shall be subjected to a gradually increasing hydrostatic pressure to the required test pressure at a rate not exceeding 300 psi (20.0 bar) per minute. The test pressure shall be maintained for 1 minute.

4.24.4 Operating Temperature (Liquid Bath)

4.24.4.1 Requirements

The operating temperature of a group of a minimum of 10 heat responsive automatic operating devices shall fall within the specified range of the nominal operating temperature. The operating temperature for all samples shall be within ±5 percent of the marked nominal temperature rating.

4.24.4.2 Test/Verification

Ten previously untested samples shall be immersed in a vessel containing water or, for nominal temperature ratings in excess of 200°F (93°C), vegetable oil.

The samples shall be placed on a grate suspended above the bottom of the vessel. The liquid level shall not exceed 1 in. (25.4 mm) above the element. The vessel shall be provided with a source for heating the liquid, a means to agitate the liquid, and a device to measure the temperature of the liquid bath. The device used to measure the temperature of the liquid bath shall be calibrated in accordance with the ASTM Standard E-1, *Standard Specification for ASTM Thermometers*, or the equivalent.

The temperature of the bath shall be raised until the liquid is 20°F (11.1°C) below the nominal temperature rating of the heat responsive element. The temperature rise shall then be controlled at a rate not exceeding 1°F (0.56°C) per minute until operation, or until a bath temperature ten percent above the nominal temperature of the sample is reached. The temperature of the liquid bath at the time of operation of each sample shall be recorded.

4.25 Supplemental Tests for Marine Applications

If considered necessary by FM Approvals, based on design features or installation requirements, the following performance requirements may supplement or supercede those listed elsewhere in this standard for marine applications. Additional tests may be required depending on design features, results of any tests, or material application, at the discretion of FM Approvals or the USCG.

4.25.1 Wiring

System wiring in a protected volume that is necessary for the system to operate and maintain the specified clean agent design concentration shall be mineral insulated.

4.25.2 Controls and Indicators

4.25.2.1 An actuation indicator, designating system discharge, shall be provided outside of an unoccupied protected space in a readily visible location. The actuation indicator is not required where the pressure gauge of an agent storage container is located outside of the protected space in a visible location. Units in unoccupied spaces shall also be provided with a pressure switch that, when operated, activates a warning light or provides a means for ventilation or engine shutdown.

4.25.2.2 A reset mechanism, located at the helm, capable of restarting the engine(s) in a protected space following engine shutdown, shall be provided for installations incorporating an engine shutdown device.

4.25.3 Vibration and Shock Resistance Tests

4.25.3.1 Requirements

A fully charged extinguishing system unit and all auxiliary system components, including the system mounting bracket, shall withstand exposure to shock and vibration, as applicable. The system shall remain operable, shall not display a potential to cause injury, shall not experience dislodgement of the system's siphon tube or displacement to other system components, shall resist leakage or cracking, and shall not experience other damage or deterioration which requires repair or replacement of the unit, mounting bracket, or system components. At minimum, the largest unit using a given bracket shall be tested.

All applicable shock and vibration tests must be run on the same sample(s). Following the completion of these tests, the system shall be successfully discharged using one of the manufacturer's compatible operating devices.

Vibration testing is required for all systems intended for marine applications. Shock testing is only required for automatic extinguisher units and pre-engineered systems.

4.25.3.2 Test/Verification

4.25.3.2.1 Vibration Test

The test sample shall be assembled in either the horizontal, lateral, or vertical orientation. The sample shall then be vibrated over the range of 10 – 60 Hz at intervals of 2 Hz at the table displacement specified below. Each frequency of vibration shall be maintained for 5 minutes.

Table 4.25.3.2.1 *Amplitude of Vibration*

Frequency of Vibration, hertz	***Table Displacement***		***Amplitude***	
	inch	***(mm)***	***inch***	***(mm)***
10 – 19	0.060 ± 0.006	(1.52 ± 0.15)	0.030 ± 0.003	(0.76 ± 0.08)
20 – 39	0.040 ± 0.004	(1.02 ± 0.10)	0.020 ± 0.006	(0.51 ± 0.05)
40 – 60	0.020 ± 0.002	(0.51 ± 0.05)	0.010 ± 0.001	(0.25 ± 0.03)

The sample shall subsequently be vibrated for 2 hours at the frequency that produced the maximum resonance observed during the initial vibration. If no resonance was initially observed, the sample shall be vibrated for 2 hours at a frequency of 60 Hz. In either case, the table displacement shall be as specified in Table 4.25.3.2.1.

Following completion of the vibration test in the first plane, the test shall be repeated in the remaining two planes until the sample has been subjected to vibration tests in all three rectilinear orientation axes.

4.25.3.2.2 Shock Resistance Test

The test sample shall be mounted on a shock machine and subjected to 5000 shock impacts. Each impact shall have an acceleration of 10g, or 322 ft/s^2 (98 m/s^2), and a duration of 20 – 25 milliseconds as measured at the base of the half sine shock envelope.

4.25.3.2.3 Vibration and Shock Resistance Post Tests

Subsequent to the completion of the vibration and shock resistance tests, the sample shall be successfully discharged using one of the manufacturer's compatible operating devices. The sample shall then be disassembled and visually inspected for damage. Mounting brackets shall be subjected to Section 4.13 (Mounting Device Test).

4.25.4 Nozzle Distribution Verification Tests

For extinguishing systems or automatic extinguisher units that are limited by a maximum volume of protection, the performance requirements described in Section 4.2 (Nozzle Distribution Verification Tests) shall be repeated with an air flow equal to one air change per minute.

For these tests, the test enclosures shall additionally include one 1 ft^2 (0.09 m^2) opening at the top of the enclosure, and one 1 ft^2 (0.09 m^2) opening within 2 ft (0.6 m) of the bottom of the enclosure; these opening sizes may not be scaled based on enclosure volume. The fan being used to provide the air exchange can either be located in the upper 1 ft^2 opening, or in a separate opening, but not in the lower 1 ft^2 opening.

These tests shall be conducted at the design concentration, rather than the minimum extinguishing concentration. Testing shall performed in both the minimum room height test enclosure, which shall include the maximum area of coverage for the unit, and the maximum room height test enclosure, which shall include the maximum specified protected volume for the unit. The extinguisher shall be conditioned to 70ºF ±5ºF (21ºC ±1.8ºC) for these tests.

4.25.5 Minimum Floor Clearance

Extinguishing systems intended for marine applications that are floor supported shall be designed to have a minimum of 2 in. (50.8 mm) of clear space between the bottom of the container and the deck to address potential corrosion concerns.

4.26 Agent Component Approval Tests

In addition to displaying successful performance in the Class A and B fire extinguishment tests of Section 4.1, a new clean agent shall undergo additional evaluations, as described below to secure component Approval. Any agent used in a system submitted for Approval shall either be component Approved for that purpose or shall be evaluated as follows on the system manufacturer's behalf.

4.26.1 Agent Acceptability for Use by Authorities Having Jurisdiction

4.26.1.1 Requirement

Clean agents shall be acceptable to the authority having jurisdiction as a prerequisite to consideration for FM Approval.

4.26.1.2 Tests/Verification

FM Approvals requires submission of the following information before any examination of extinguishing capabilities of an agent will be undertaken:

For agents to be used in North America, listing by the United States Environmental Protection Agency (EPA) as an Acceptable Substitute under their Strategic New Alternatives Program (SNAP) shall be in place. This addresses both acceptability of ozone depletion potential (ODP) and suitability for use in occupied spaces under the Toxic Substance Control Act (TSCA). The neat agent will require independent testing by a recognized biological testing laboratory to provide the data required by the EPA to determine acceptability.

If, in the interest of expedience, a manufacturer wishes to pursue an FM Approval program concurrent with obtaining EPA SNAP acceptance for their extinguishant, at minimum, documentation showing that independent laboratory studies are in progress to generate the data required for submission to the EPA under the SNAP program must be submitted. All examination contracts written under these circumstances will remind the Client that Approval will be contingent upon EPA acceptability, and that success in other aspects of the examination shall, in no way, supersede this requirement.

For agents to be used outside of North America, any relevant similar local acceptance must also be in place.

The agent shall also be specifically included in NFPA 2001, or equivalent local jurisdictional standard.

The AHJ listed minimum extinguishing concentration and No Observable Adverse Effect Level (NOAEL) will be used to define the agent's FM Approvals listing.

4.26.2 Metals Compatibility

4.26.2.1 Requirement

Clean extinguishing agents shall be compatible with metals commonly used in fire protection systems or intended for use with the agent.

4.26.2.2 Tests/Verification

Two 1 in. (25 mm) diameter coupons of each test metal shall be exposed to 100 percent extinguishing agent vapors in an enclosed 16 liter polycarbonate chamber at ambient pressure and temperature for 7 days. At minimum, test coupons will include 0.002 in. (0.05 mm) thick copper, 0.002 in. (0.05 mm) thick steel, and 0.001 in. (0.03 mm) thick aluminum. Weight change of each coupon shall be measured. There are no pass/fail criteria for this test. Results are used to assess the need for further testing when the agent is used in systems if the agent appears aggressive toward a general type of metal used in the system under evaluation.

4.26.3 Polymer Compatibility

4.26.3.1 Requirement

Clean extinguishing agents shall be compatible with polymers commonly used in fire protection systems or intended for use with the agent.

4.26.3.2 Tests/Verification

Two 1 in. diameter, 0.0625 in. thick (25 mm diameter x 1.6 mm) coupons of each polymer shall be exposed to 100 percent extinguishing agent vapors in an enclosed 16 liter polycarbonate chamber at ambient pressure and temperature for 7 days. At minimum, Viton (fluorocarbon), Neoprene, Silicon, and Polyurethane rubbers shall be tested. Change in weight (gain or loss) shall be measured. There are no pass/fail criteria for this test. Results are used to assess the need for further testing when the agent is used in systems if the agent appears aggressive toward a general type of polymer used in the system under evaluation.

4.26.4 Agent Suitability Tests

4.26.4.1 Requirement

Clean agents shall demonstrate suitability for service comparable to Halon 1301, at minimum, through either:

a) Compliance with Section 4.26.1, or
b) Compliance with Section 4.26.4.2

4.26.4.2 Tests/Verification

If compliance with Section 4.26.1 is not met, clean agents shall demonstrate satisfactory performance when tested per National Institute of Standards and Technology (NIST) Technical Note 1278, *Preliminary Screening Procedures and Criteria for Replacements for Halons 1211 and 1301*, including, residue level, stability under long-term storage, and electrical conductivity.

These tests must be witnessed by an FM Approvals representative, performed by FM Approvals, or performed by an independent laboratory acceptable to FM Approvals.

4.26.5 Agent Quality

4.26.5.1 Requirement

Clean agents shall meet the quality requirements of Table 4.26.5.1, as verified using industry standard analytical methods (e.g., ASTM, AHRI), unless the authority having jurisdiction sets more stringent requirements. In such cases, the more stringent requirements shall pertain.

Table 4.26.5.1 *Clean Agent Quality Requirements*

Agent Type	***Property***	***Requirement***
Halocarbon	Purity, mole percent, minimum	99.0
Halocarbon	Acidity, ppm, by weight (HCl equivalent), maximum	3.0
Halocarbon	Water content, weight percent, maximum	0.001
Halocarbon	Nonvolatile residues, g/100 ml, maximum	0.05
Inert Gas (monomolecular)	Purity, volume percent, minimum	99.9
Inert Gas (blend)	Blend component percentages	Manufacturer's Specification (At the sole discretion of FM Approvals, extinguishment tests may be run at any extreme of composition within this specification.)
Inert Gas (all)	Water content, weight percent, maximum	0.005

4.26.6 Agent Identification Benchmarking

4.26.6.1 Requirement

The agent shall be subjected to a Fourier transform infrared spectroscopy (FTIR) analysis to obtain a benchmark profile for future reexamination reference.

4.26.6.2 Tests/Verification

A sample of each clean agent submitted for Approval shall be subjected to a Fourier Transform Infrared (FTIR) analysis. This sample shall be taken from the same lot of agent as used in the fire extinguishment tests. This analysis shall be conducted in the FM Global Research laboratory or at another competent laboratory with witnessing by an FM Approvals representative. The resulting spectrum shall be retained by FM Approvals for use in identifying deviations from the as-Approved composition, either through formulation changes, production process faults, or contamination of installed systems.

4.26.7 Class A Extinguishing Capability

4.26.7.1 Requirement

The agent shall be evaluated to determine the Class A extinguishing capability.

4.26.7.2 Tests/Verification

The extinguishing concentration (volume percent) shall be determined for diffusion flames of black PMMA (3.75 in. diameter and 1 in. thick in a standard insulated sample holder) in the Fire Propagation Apparatus (ASTM E2058/ISO 12136). The PMMA sample surrounded by a 6.5-in. diameter quartz tube will be exposed to a maximum 40 kW/m^2 radiant heat flux. When the chemical heat release rate reaches a steady value, an increasing volume percent of the extinguishing agent will be introduced into the quartz tube of the test apparatus until flame extinction occurs to determine the extinguishing concentration.

4.27 Class C Extinguishing Capability and Products of Decomposition

4.27.1 Requirement

Clean Agents shall be used to protect Class C hazards in concentrations proven to be suitable for the specific hazard and only in situations where the products of decomposition are tolerable.

4.27.2 Tests/Verification

FM Approvals and others in the fire protection community are attempting to develop appropriate tests to assess Class C extinguishing capability for clean agents. At present, no clear consensus exists on a test method. FM Approvals is also concerned with the products of decomposition that are generated when clean agents are used on hazards involving persistent sources of ignition energy. Until acceptable methodology is developed, there will be no required evaluation for these characteristics.

Appendix G describes the method used to evaluate the ability of various clean agents to suppress combustion in PMMA sheathes on the electrodes, and to generate products of decomposition for analysis and quantification. This testing is available to interested clean agent manufacturers who wish to compare the performance of their products to that of Halon 1301, but this is not a requirement for Approval.

When appropriate test methodology has been developed, this section will be revised to address Class C extinguishing capability and measurement of products of decomposition. This testing will then become a requirement for FM Approval of clean agents.

4.28 Additional Tests

Additional tests may be required, at the discretion of FM Approvals, depending on design features and results of any foregoing tests. A retest following a test failure shall be acceptable only at the discretion of FM Approvals, and with adequate technical justification of the conditions or reasons for failure.

5. OPERATIONS REQUIREMENTS

A quality assurance program is required to assure that subsequent systems produced by the manufacturer shall present the same quality and reliability as the specific system(s) examined. Design quality, conformance to design, and performance are the areas of primary concern:

- Design quality is determined during the examination and tests, and is documented in the Approval Report
- Continued conformance to this standard is verified by the Surveillance Audits
- Quality of performance is determined by field performance and, as necessary, by periodic re-examination and testing

5.1 Demonstrated Quality Control Program

5.1.1 The manufacturer shall demonstrate a quality assurance program that specifies controls for, at minimum, the following areas:

- Existence of corporate quality assurance guidelines
- Incoming quality assurance, including testing
- In-process quality assurance, including testing (if applicable)
- Final inspection and tests
- Equipment calibration
- Drawing and change control
- Product labeling
- Packaging and shipping
- Handling and disposition of nonconforming materials

5.1.2 Documentation/Manual

There shall be an authoritative collection of quality procedures and policies. Such documentation shall provide an accurate description of the quality management system and serve as a permanent reference for implementation and maintenance of that system. The system should require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system. FM Approvals Approval Standard, *Quality Assurance Guidelines for Manufacturers of FM Approved and Specification Tested Products*, September 2003, should be referenced.

5.1.3 Records

To ensure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, and shall maintain this record for a minimum period of two years from the date of manufacture.

5.1.4 Drawing and Change Control

The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the Approval Report, must be reported to, and authorized by, FM Approvals prior to implementation for production.

The manufacturer shall assign an appropriate person or group to be responsible for reporting proposed changes to FM Approved or Listed products to FM Approvals prior to implementation. The manufacturer shall notify FM Approvals of changes to the product or of persons responsible for keeping FM Approvals advised by means of FM Approvals Form 797, FM Approved Product/Specification-Tested Revision Request Form. Records of all revisions to all FM Approved products shall be maintained.

5.2 Surveillance Audits – General

5.2.1 An initial surveillance audit of the manufacturing facilities is part of the Approval investigation to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are implemented and maintained to ensure a uniform product consistent with that tested and FM Approved.

5.2.2 Each facility shall then remain part of the FM Approvals Surveillance Audit program as a condition of ongoing Approval. Surveillance audits shall be conducted quarterly by FM Approvals or its representatives, or more frequently dependent on jurisdictional requirements.

5.2.3 FM Approved products or services shall be produced at or provided from only the location(s) audited by FM Approvals, and as specified in the Approval Report. Manufacture of products bearing the FM Approvals Certification Mark is not permitted at any other location without prior written authorization by FM Approvals.

5.3 Surveillance Audits – Filling Facilities

5.3.1 All facilities utilized by a manufacturer to fill FM Approved clean agent systems must have an initial surveillance audit performed as part of the Approval investigation.

5.3.2 Each facility shall then remain part of the FM Approvals Surveillance Audit program as a condition of ongoing Approval. At a minimum, surveillance audits shall be conducted annually by FM Approvals or its representatives. Depending on the extent and complexity of the procedures, and/or jurisdictional requirements, more frequent audits may be required at the sole discretion of FM Approvals.

5.3.3 Each filling facility shall be audited to ensure they meet the following requirements, at a minimum:

5.3.3.1 Facilities must have and utilize documentation of the filling procedure(s), as applicable, controlled by the manufacturer of the Approved system. This procedure should address assembly, temperature compensation, leak checking, proper blending for inert gas agents, and/or pressurization for liquefied gas agents, including agitation and hold period, as applicable.

5.3.2.2 Facilities must demonstrate quality control of critical components such as seals, valves, and agent storage containers, and have a procedure in place for non-conforming material. Alternatively, the manufacturer of the Approved system may supply complete assemblies for filling.

5.3.2.3 Agent storage containers being filled must be up to date on all qualifications and examinations in accordance with the recognized international standard(s) appropriate to each container.

5.3.2.4 The clean agent shall be traceable as FM Approved through lot/batch numbers and/or agent manufacturer’s quality reports, as applicable.

5.3.2.5 Facilities must have a procedure in place to avoid contamination during the filling process.

5.3.2.6 Any instrumentation used for filling must be properly calibrated, and be of the appropriate range and legibility to ensure accurate measurements.

5.3.2.7 At a minimum, the following information should be recorded for each fill and properly maintained for traceability:

- Unique agent storage container or system/assembly serial number
- Order number and customer (may be recorded at a later date, as long as its traceable back to the fill)
- Fill date
- Employee name

- Empty agent storage container assembly weight
- Ambient Temperature
- Agent Temperature
- Agent fill weight and/or pressurization level, as applicable
- Filled agent storage container assembly weight
- Leak test results

5.4 Installation Inspections

Field inspections may be conducted to review an installation. The inspections are conducted to assess ease of application and conformance to written specifications. When more than one application technique is used, one or all may be inspected at the discretion of FM Approvals.

5.5 Manufacturer's Responsibilities

The manufacturer shall provide complete instructions for the usage and recharge of systems. The instructions shall provide specific quality assurance procedures on the use of calibrated equipment, such as scales, pressure gauges, and other critical equipment, in the recharging of a system.

5.6 Manufacturing and Production

5.6.1 The manufacturer shall design systems in accordance with NFPA 2001 and/or any other standard specifically referenced in the Approval report and listing.

5.6.2 The manufacturer shall fabricate and test pressure cylinders in accordance with the standard(s) referenced in the Approval report and listing.

5.6.3 The manufacturer shall leak test all filled agent storage containers prior to release for shipment. The leak test method shall employ appropriately calibrated and sensitive leak detection devices.

5.6.4 The manufacturer shall only fill storage containers with clean agent meeting the requirements of NFPA 2001.

5.7 Design, Installation, Operating, and Maintenance Manual

5.7.1 A design, installation, operation, and maintenance manual shall be provided with each extinguishing system, or be made available upon request. A copy of the manual shall be provided to FM Approvals as a reference prior to the examination and testing of the system. Subsequent to the successful completion of the examination, an electronic copy of the manual shall be provided to FM Approvals for reference in the review of systems proposed for installation in FM Global insured properties. This manual may be shared within FM Global, as needed, for its property loss prevention engineering. Updated electronic copies of the manual shall be provided to FM Approvals as revisions are made.

5.7.2 The manual shall include the following information, at a minimum, if applicable:

- Manufacturer’s name and address.
- Date and part number designation on each page of the manual.
- Description of equipment and accessories, including part numbers and model numbers.
- Description of the clean agent design concentration
- Material Safety Data Sheets
- Piping and fitting limitations, including equivalent length values, if applicable

- Discharge nozzle limitations, including maximum area of coverage, minimum and maximum installation height, nozzle location, and minimum design pressure
- For engineered systems, a description of the calculation method and a sample problem including all required input and calculated output, limitations on the percent of clean agent in the pipe, minimum and maximum flow rates in the pipe, and method for discharge nozzle selection including flow information and minimum and maximum orifice area limitations
- System configuration limitations and installation instructions
- Detection devices and control panels for use with the extinguishing system
- Range of filling weights for each agent storage container size.
- Instructions regarding the connection of multiple agent storage containers
- System working pressure at 70°F (21°C)
- Allowable ambient storage temperature range, including pressure vs. temperature references for the range of fill densities
- Inspection requirements
- Maintenance requirements
- Recharge instructions
- Reference to NFPA 2001, Standard for Clean Agent Extinguishing Systems, or other relevant local standards
- Venting requirements for the hazard enclosure to avoid damage due to excessive positive or negative pressure differentials
- Acceptance test form to document satisfactory operational status of the system upon completion of installation
- Guidance on the design, installation, and usage of extract systems to ventilate enclosures after system discharge
- A clearly labeled section listing any part numbers included in the manual, but not within the scope of the FM Approval

APPENDIX A: Units of Measurement

AREA: in^2 – "square inches"; (mm^2 - "square millimeters")
$mm^2 = in^2 \times 6.4516 \times 10^2$

ft^2 – "square feet"; (m^2 - "square meters")
$m^2 = ft^2 \times 0.0929$

FLOW RATE: gal/min – "gallons per minute"; (L/min - "liters per minute")
L/min = gal/min x 3.785

FORCE: lb – "pounds", (N - "newtons")
N = lb x 4.448

HEAT: Btu – "British thermal units"; (J - "joules")
$J = Btu \times 1.0551 \times 10^3$

HEAT RELEASE RATE: Btu/min – "British thermal units per minute"; (kW - "kilowatts")
kW = Btu/min x 0.0176

LENGTH: in. – "inches"; (mm - "millimeters")
mm = in. x 25.4

ft – "feet"; (m - "meters")
m = ft x 0.3048

MASS: lb – "pounds"; (kg - "kilograms")
kg = lb x 0.454

PRESSURE: psi – "pounds per square inch"; (bar - "bar")
kPa = psi x 6.895
bar = psi x 0.06895

TEMPERATURE: °F – "degrees Fahrenheit"; (°C - "degrees Celsius")
°C = (°F - 32) x 0.556

TORQUE/MOVEMENT lb·ft – "pound-feet" (N·m – "Newton-meters")
N·m = lb·ft × 1.356

VOLUME: gal – "gallons"; (L - "liter")
L = gal x 3.785

APPENDIX B: Tolerances

Unless otherwise stated, the following tolerances shall apply:

Angle:	±2°
Frequency (Hz):	±5 percent of value
Length:	±2 percent of value
Volume:	±5 percent of value
Rotation:	±1 RPM
Pressure:	±3 percent of value
Temperature:	±3°F
Time:	+5/–0 seconds +0.1/–0 minutes +0.1/–0 hours +0.25/–0 days

Unless stated otherwise, all tests shall be carried out at a room (ambient) temperature of 68 ± 9°F (20 ± 5°C).

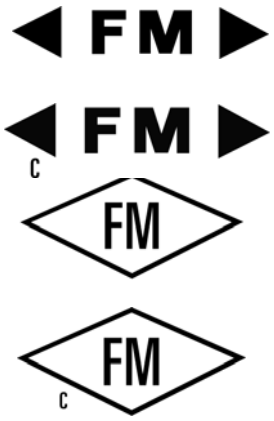
APPENDIX C: FM Approvals Certification Marks

FM Approvals certifications marks are to be used only in conjunction with products or services that have been FM Approved by FM Approvals and in adherence with usage guidelines.

FM APPROVED mark:
Authorized by FM Approvals as a certification mark for any product that has been FM Approved. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.

FM APPROVED mark with "C" only:
Authorized by FM Approvals as a certification mark for any product that has been evaluated by FM Approvals in accordance with Canadian codes and standards. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.

FM APPROVED mark with "C" and "US":
Authorized by FM Approvals as a certification mark for any product that has been evaluated by FM Approvals in accordance with US and Canadian codes and standards. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.



Cast-On FM APPROVALS marks:
Where reproduction of the FM APPROVED mark described above is impossible because of production restrictions, use these modified versions of the FM APPROVED mark. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable.

Downloadable art and other FM Approvals resources are available by visiting our Web site at www.fmapprovals.com

FM Approvals Certification Marks

Usage Guidelines

- All FM Approvals certification marks are the sole property of FM Approvals LLC ("FM Approvals") and are registered or the subject of applications for registration in the United States and many other countries. They are for use only according to these guidelines.
- FM Approvals certification marks may be used only on FM Approved products and related product packaging, in advertising material, catalogs and news releases. Use of FM Approvals certification marks on such material is not a substitute for use of the complete FM Approvals certification mark on FM Approved products and/or product packaging.
- No FM Approvals certification mark or aspect thereof may be incorporated as part of a business name, Internet domain name, or brand name/trademark for products/product lines. This includes both design aspects (the FM Approvals "diamond," etc.) and word aspects ("FM," "Approved," etc.). The use of any FM Approvals certification mark as a trademark is strictly prohibited.
- The Approval Standard number or class number may not be incorporated as part of a business name, Internet domain name, or brand name/trademark for products/product lines. For example, a company may not say "ABC Company's 4100 Fire Door is FM Approved"; the proper terminology is, "ABC Company's Fire Door is FM Approved per Approval Standard 4100."
- FM Approvals certification marks, except for the FM Approvals Quality System Registration mark, may not be used on business stationery/cards/signage because this could mischaracterize the relationship with FM Approvals. Additionally, these items should not reference any FM Approvals certification mark.
- Products or services may not be marketed under any mark or name similar to "FM Global," "FM Approvals" or any of the FM Approvals certification marks. Further, products or services may not be marketed to imply a relationship beyond the scope of any Approval made by FM Approvals.
- When an FM Approvals certification mark is used in advertising material or on product packaging, all material must reflect the specific circumstances under which the product was FM Approved. The material must clearly differentiate between products that are FM Approved and those that are not, and may not, in any way, imply a more substantial relationship with FM Approvals.
- A company may not reference the intent to submit a product for Approval or the expectation that a company will have a certain product FM Approved in the future. For example, a company may not state, "Approval by FM Approvals pending" or "Approval by FM Approvals applied for."
- FM Approvals certification marks should not be preceded or followed by a qualifier that indicates a degree of certification or acceptability. For example, "exceeds," "first" or "only" may not be used to qualify any FM Approvals certification mark.
- Only original artwork issued by FM Approvals should be used. The FM Approvals certification marks should not be altered in any way other than to resize the artwork proportionately. Unacceptable uses of the marks include, but are not limited to, adding/deleting wording or artwork, reducing the artwork to an illegible size, animation or distortion.
- The text of the FM Approvals certification marks may not be translated into any language other than English.
- FM Approvals certification marks must appear in a size and location that is readily identifiable, but less prominent than the name of the owner of the certification or the manufacturer/seller/distributor of the certified products.

APPENDIX D: Tolerance Limit Calculations

Using the data obtained as described in Sections 4.24.1 (Assembly Load/Frame Strength) and 4.24.2 (Strength of Heat Responsive Element), the mean and standard deviation for the assembly load and the bulb strength shall be calculated using the following equation:

$$\sigma_{n-1} = \left[\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right]^{1/2}$$

where:

σ_{n-1} = standard deviation
x = sample mean
x_i = individual values of each sample tested
n = number of samples tested

Based on the number of devices or bulbs tested (n), a value, γ, shall be selected from Table D1 where the degree of confidence is 0.99 and the proportion of samples is 0.99.

Table D1 *γ Factors for One-Sided Tolerance Limits for Normal Distributions (99 Percent of Samples)*

n	***γ***	***n***	***γ***	***n***	***γ***
10	5.075	17	4.038	24	3.638
11	4.828	18	3.961	25	3.601
12	4.633	19	3.893	30	3.446
13	4.472	20	3.832	35	3.334
14	4.336	21	3.776	40	3.250
15	4.224	22	3.727	45	3.181
16	4.124	23	3.680	50	3.124

Tolerance limits shall then be calculated as follows:

$$LTL = \bar{x}_B - \gamma_B \sigma_{(n-1)B}$$

$$UTL = \bar{x}_S - \gamma_S \sigma_{(n-1)S}$$

where:

LTL = lower tolerance limits for device strength
UTL = upper tolerance limit for assembly load
$\bar{x}_B$ = mean device strength
γ_B = device strength factor (γ) from Table D1
$\sigma_{(n-1)B}$ = sample unbiased standard deviation for the bulb
$\bar{x}_S$ = mean assembly load
$\sigma_{(n-1)S}$ = sample unbiased standard deviation for the assembly load
γ_S = assembly load factor (γ) from Table D1

Compliance with the requirement shall be confirmed if LTL > UTL.

Outliers may be discarded from the sample base utilizing appropriate statistical techniques at the discretion of FM Approvals.

APPENDIX E: Figures

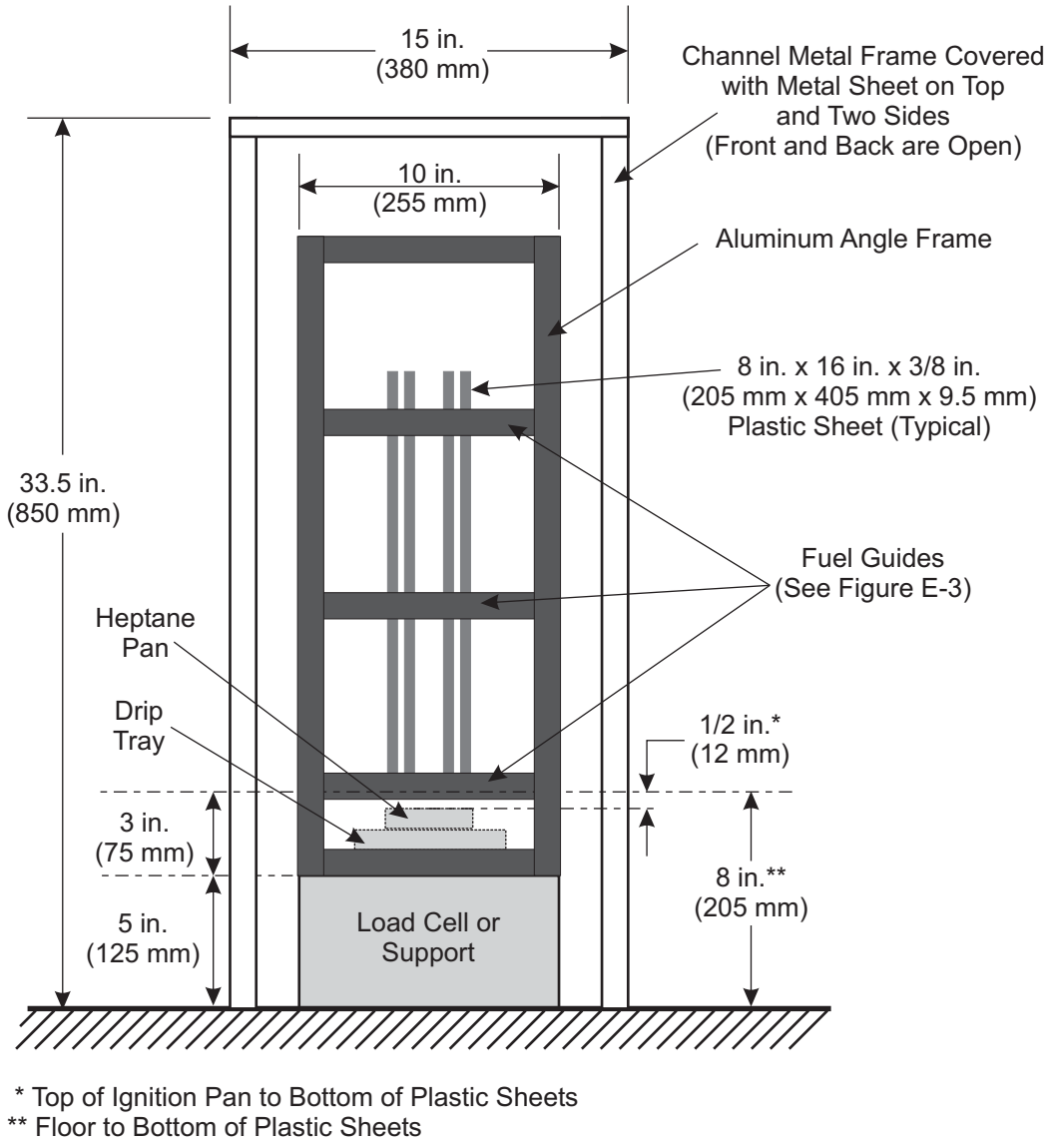
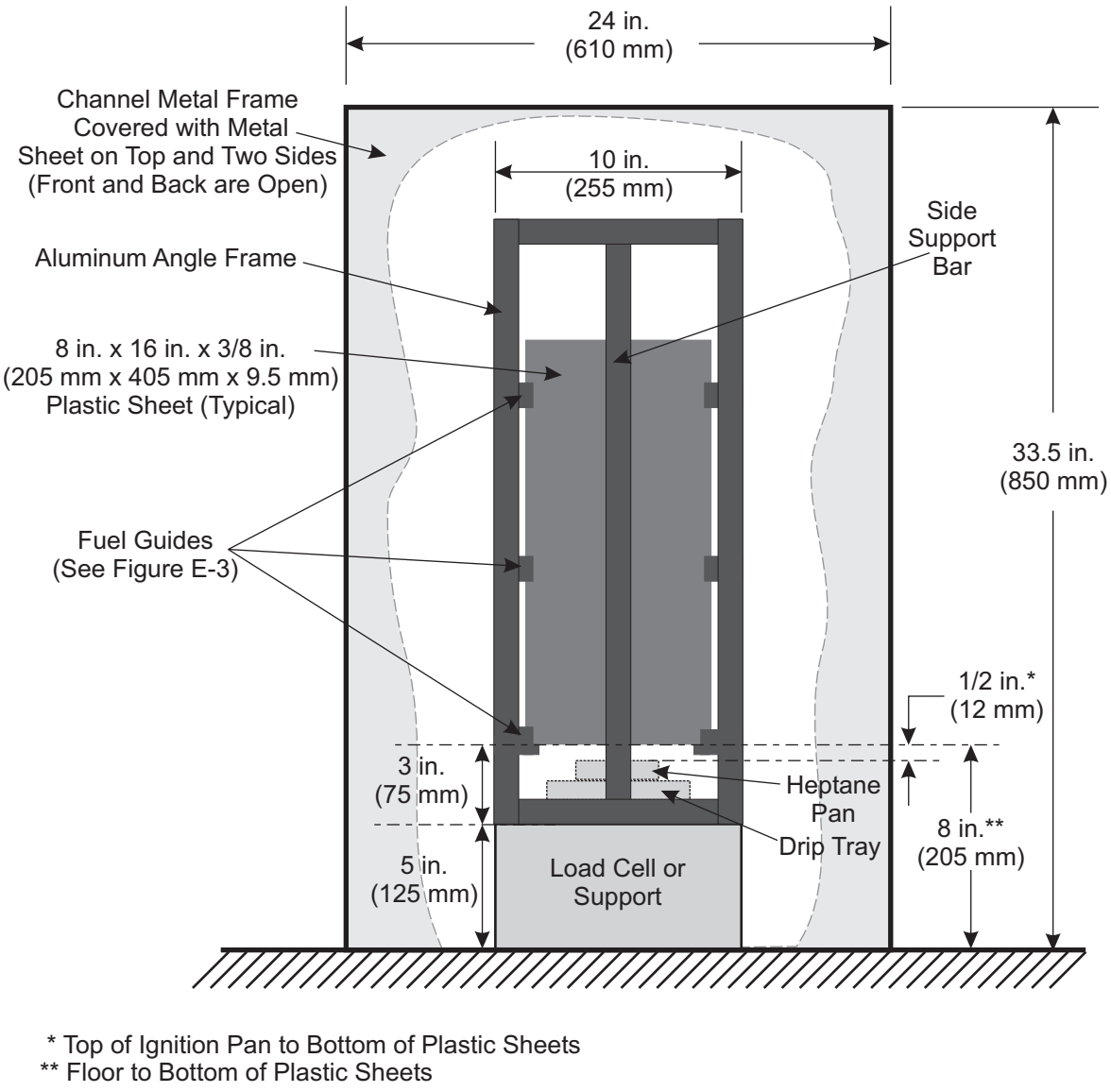


Figure E-1. Fuel Array and Inner Baffle - Front View



* Top of Ignition Pan to Bottom of Plastic Sheets
** Floor to Bottom of Plastic Sheets

Figure E-2. Fuel Array and Inner Baffle - Side View

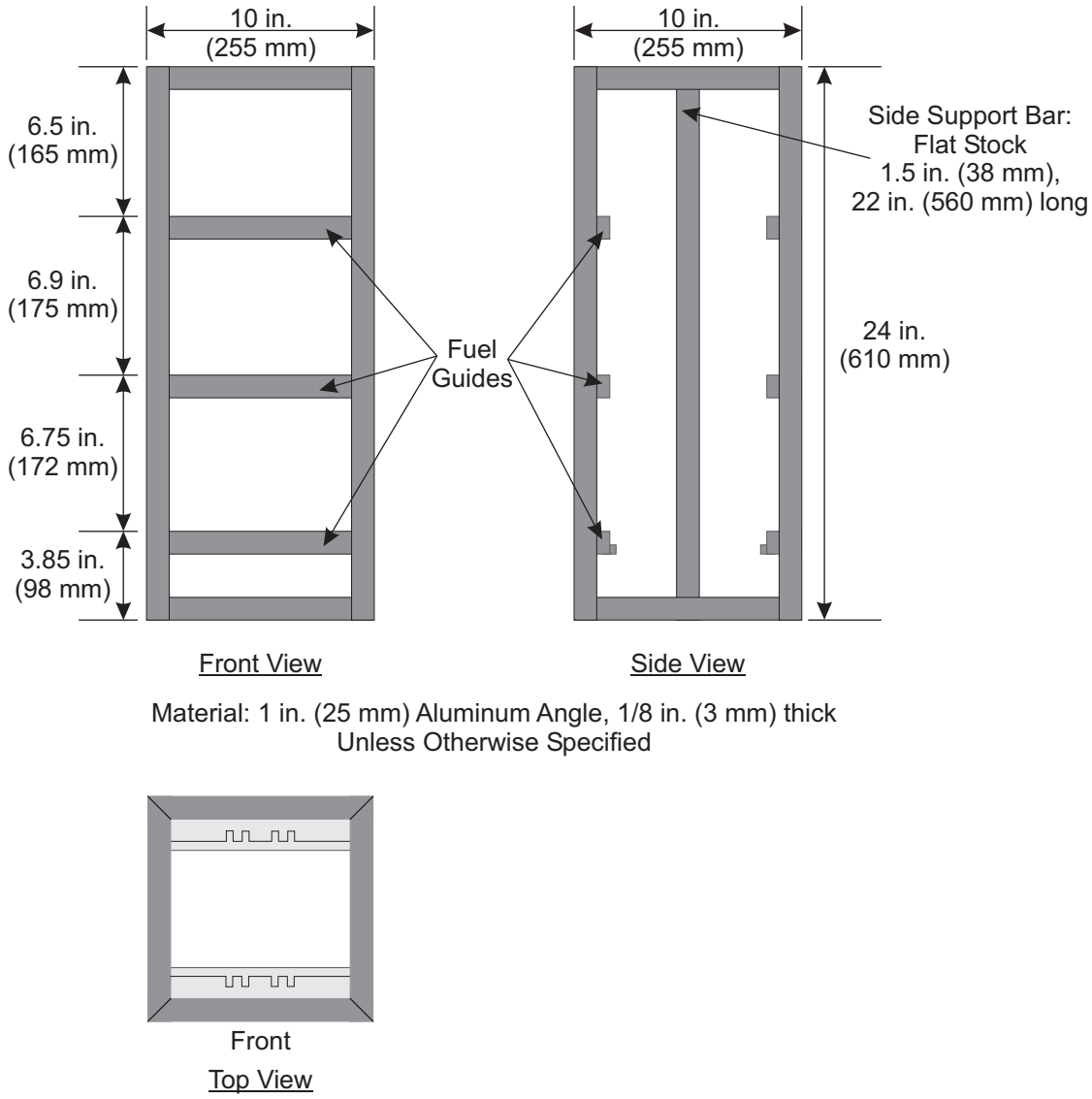


Figure E-3. Fuel Array and Inner Baffle - Detail View

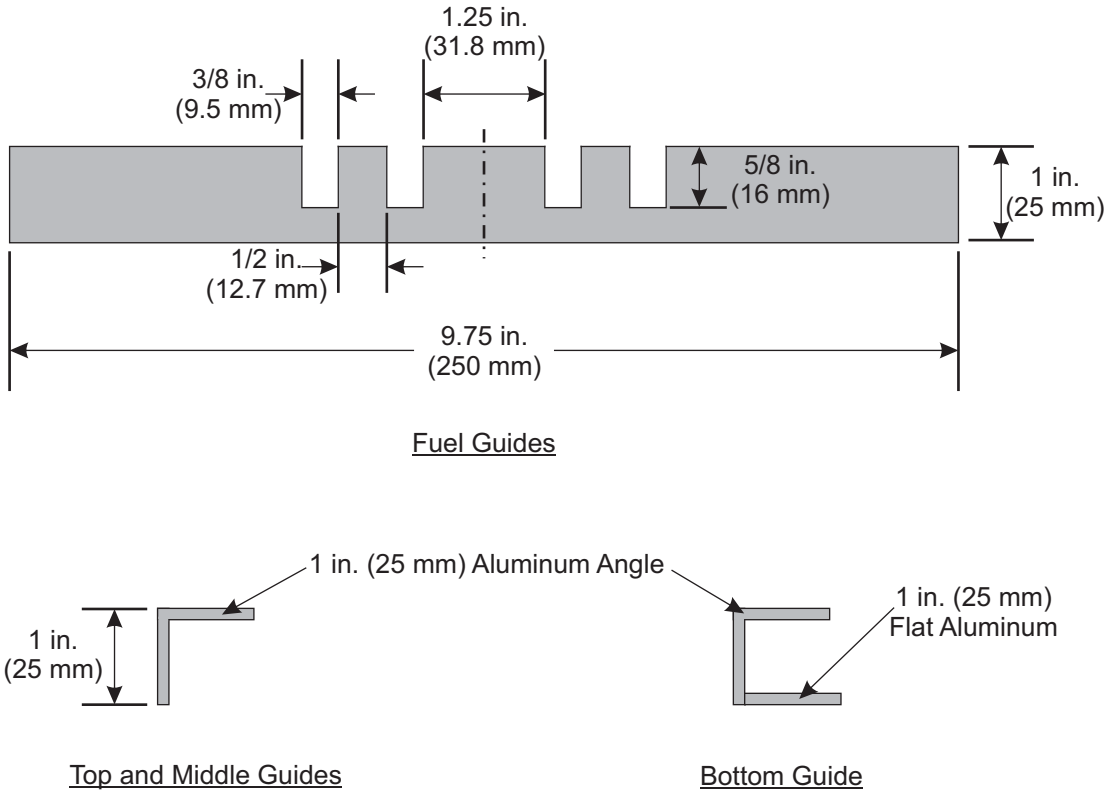
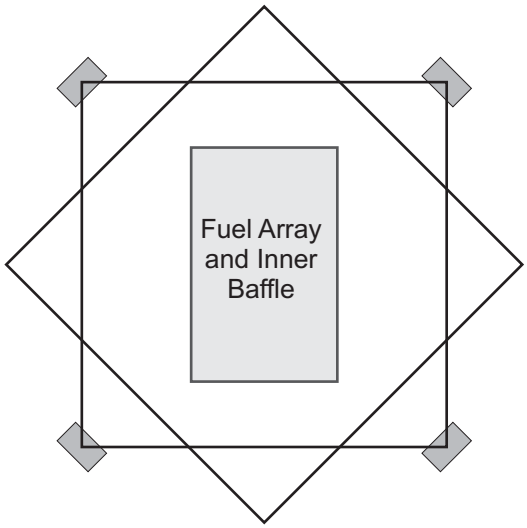
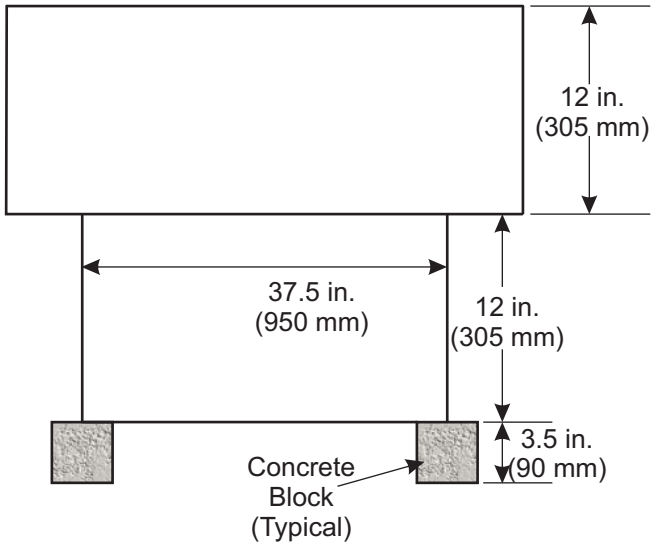


Figure E-4. Fuel Guides



Test Array Top View



Test Barrier Side View

Figure E-5. Outer Baffle

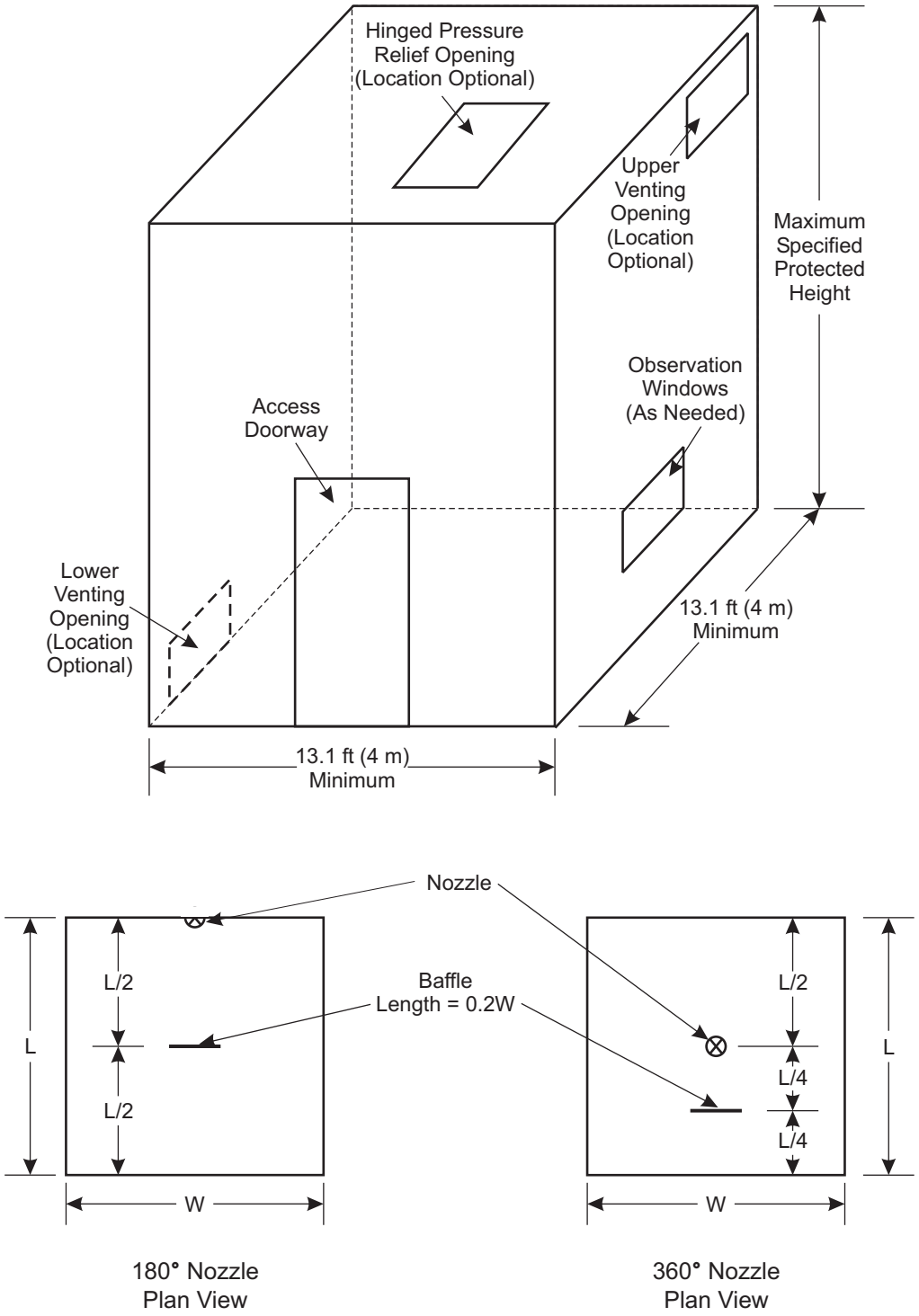
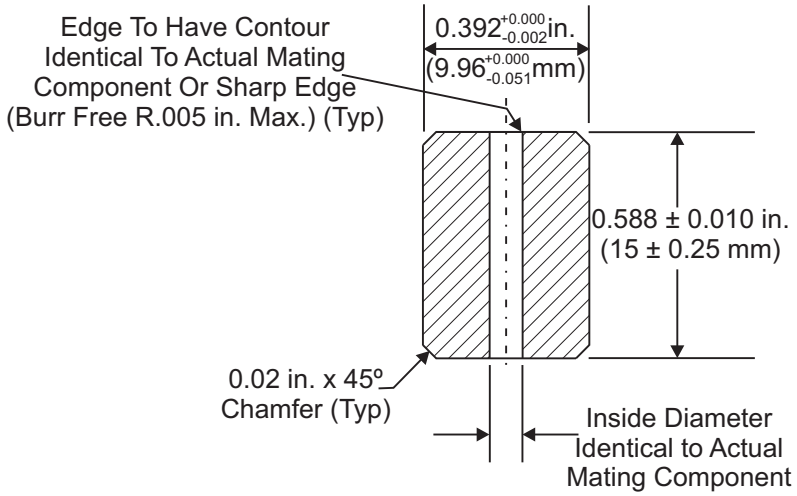
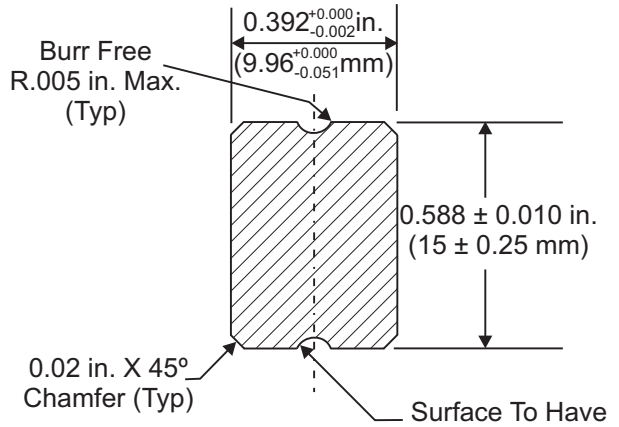


Figure E-6. Test Enclosure

For Designs with Line Contact:



Or: For Designs with Surface Contact:



REQUIRED:
* Material - Hardened Steel, Rockwell C38 - 50
* Markings - Manufacturer, Bulb Size, Seat Diameter

Figure E-7: Bulb Crush Inserts For Strength of Element Test

APPENDIX F: Sample Approval Guide Listings

Approval Guide listings for clean extinguishing agents shall include:

- Manufacturer's product name
- Chemical name
- Any commonly used designations used in relevant jurisdictional standards
- Extinguishing capability, including minimum Class A and Class B extinguishing concentrations
- Approximate lethal concentration (ALC)
- No observed adverse effects level (NOAEL)
- Lowest observable adverse effects level (LOAEL)
- Any restrictions on usage

Approval Guide listings for clean agent extinguishing systems shall include:

- Manufacturer's designation for system
- Type of system (Pre-engineered, Engineered, Balanced, Unbalanced, Automatic Extinguisher)
- Identification of clean agent used
- Minimum and maximum agent storage temperatures
- Minimum and maximum temperature of protected spaces
- Minimum and maximum nozzle heights
- Types of nozzles available (180º, 360º, other)
- Maximum area of coverage and reach for each type of nozzle
- Minimum design concentrations for each hazard class
- Minimum and maximum discharge times
- Design, installation, operation, and maintenance manual identification by title, part number, issue date, revision level, and paragraph or section reference in the manual to a list of any part numbers included in the manual, but not within the scope of the FM Approval
- Design software title, part number, and version level (engineered systems only)
- Design software user's manual title, part number, issue date, and revision level
- Any limitations to the Approval or exceptions to the listed manuals, software, or other documents
- Approved filling station locations

APPENDIX G: A Method of Testing the Effectiveness of Clean Agents in Suppressing Cable Fires Ignited by a Sustained Electrical Arc

A schematic diagram of the apparatus is shown in Figure G-1. The testing is to be conducted in an airtight test chamber constructed of 1/2 in. nominal thick polycarbonate panels cemented together to form a box with a removable, gasketed cover. The inside volume of the chamber is 1 ft^3 (0.0283 m^2).

A predetermined amount of the extinguishing gas is to be introduced through a port, using a calibrated flow meter. A vaporizing liquid extinguishant with a very low vapor pressure will be introduced as a weighed sample of liquid in an open dish and evaporated by use of a small fan until no liquid is visible in the dish. The same fan is to be used to maintain uniform agent-air mixture. The fan is to be rated at 9 ft^3/min (0.25 m^3/min). It is installed in one bottom corner of the chamber, blowing upward, and is operated throughout the duration of a test.

The mixture in the chamber is sampled through three ports, one each at the bottom, top, and mid height. The samples are monitored by a gas analyzer.

Two nominal 12 in. long, 1/4 in. diameter copperclad carbon electrodes are introduced approximately in the center of the chamber through sealed openings in opposite walls. One electrode is held fixed, while the other is connected to a linear positioning device, indicated as the arc adjuster in the schematic. The adjuster is used to control the gap between the two electrodes to sustain an arc.

A welding machine is used to supply direct current to generate continuous arcing. Input voltage and current are adjusted by use of the welder's controls and monitored by calibrated volt and ampere meters. The voltage is held a 50 V and the current at 40 A by use of the welder's controls and adjusting the gap between the electrodes. The gap may grow from approximately 1/16 in. to approximately 1/8 in. during the course of a test due to erosion of the electrodes.

PMMA (polymethylmethacrylate) sheathing approximately 3 in. long and 1/2 in. outside diameter x 1/4 in. inside diameter is placed around the electrodes. The sheathes are positioned approximately 1/4 in. from the ends of the electrodes.

Experiments are conducted at various agent concentrations. The times for ignition and extinguishment of the PMMA sheathes are visually observed. The minimum concentrations to extinguish the PMMA are determined by repeated experiments.

In addition, the decomposition products (F, Br, and Cl ions) are quantified.

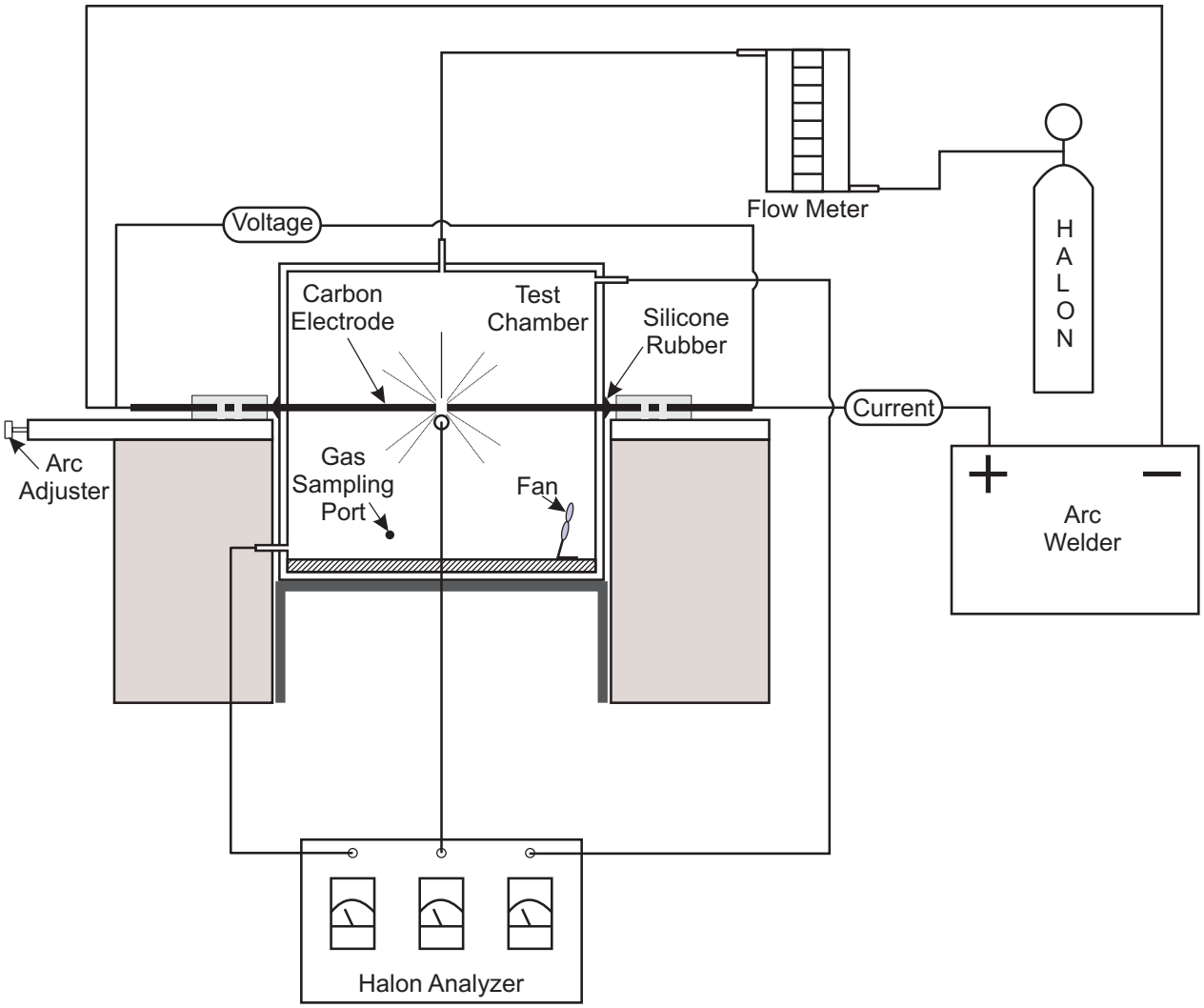


Figure G-1: Test Apparatus